The Marine Laboratory

UNIVERSITY OF MIAMI

53-9

A Technical Report
1 June 1953

to

The Office of Naval Research
Contract Nonr-840(01)

TROPICAL OCEANOGRAPHY

CORAL GABLES, FLORIDA

SOME RESULTS OF THE FLORIDA CURRENT SURVEY
15 November 1952 to 15 May 1953

by

Lansing P. Wagner
and
Frank Chew

53-9

A Technical Report
1 June 1953

to

The Office of Naval Research
Contract Nonr-840(01)

TROPICAL OCEANOGRAPHY

Submitted by

THE MARINE LABORATORY
University of Miami

Coral Gables, Florida
ML 5214

F. G. Walton Smith
Director

TABLE OF CONTENTS

LIST OF PLATES

LIST OF FIGURES

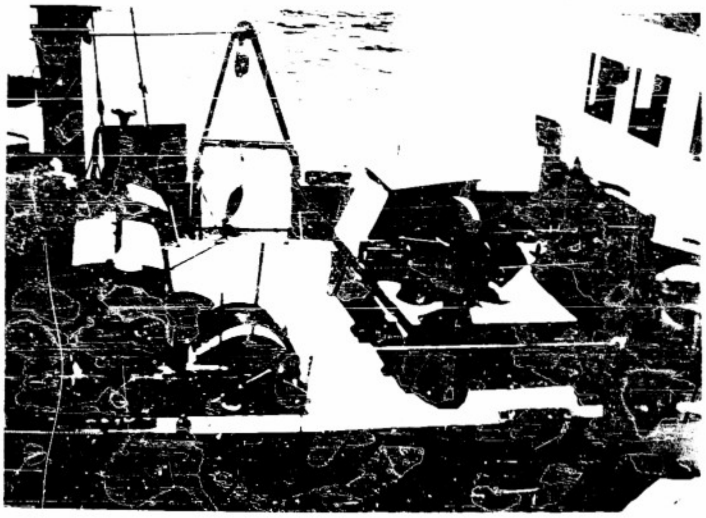


Plate 2
Hydro Winch on Foredeck

Plate 1
The Research Vessel T-19

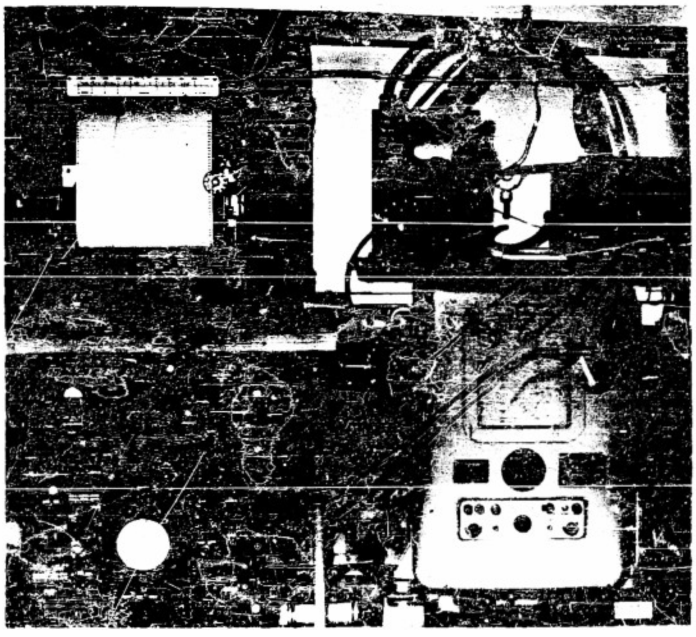


Plate 3
Gear Installed in
After Lab

ABSTRACT. Temperature and current measurements have been made during transects of the Florida Current. Temperature variations that may correspond with the tide or with internal waves have been noted on the western side of the Current. Seasonal variations also show up. Often, cooling of a water column is associated with a more rapid temperature change. Each section on the Florida Current, transversewise, produces a characteristic bathythermogram.

Surface currents were measured by means of a geomagnetic electrokinetograph. Monoaxial and biaxial current patterns were found. On the western side of the axis occurs the greatest horizontal surface velocity shear, and associated with that is the greatest horizontal temperature change at 100 and 200 meters. Near the western edge there is indication that greater average speed is associated with greater net surface change of temperature.

Determinations of transport have been attempted by means of the Malkus-Stern theory. There is a strong relation between transport and the cross-sectional area above the first strong thermocline. As yet, no obvious relation between transport and average surface velocity has been observed. A slight deepening of the first strong thermocline below the speed axis of the current has been noticed.

Observations made along the western edge of the Florida Current and in the area west of Eleuthera Island, the "Antilles Current" area, are incorporated in this report.

INTRODUCTION

A series of temperature and velocity measurements across the Florida Current was started towards the end of December, 1952 in an attempt to discover and understand the variations - seasonal, lunar, diurnal and meteorological - in temperature, velocity and current location that have been noticed in this body of water. The research vessel of the Marine Laboratory used in this investigation is the U.S. Army T-19. (Plate 1.) Its overall length is 65 feet, with a beam of 16 feet, and is powered by a Superior MRD-6 diesel engine. It accommodates four scientists and two crew members. The T-19 is equipped with the following hydrographic gear, which is being used in this investigation:

Hydrographic winch, wire and Nansen bottles
Bathythermograph winch, wire and bathythermographs
Geomagnetic Electrokinetograph (GEK)

Fathometers (NMC-1) and (UQN-16)
Loran
Meteorological instruments
RDF (recently installed)

The timing and spacing of this series of cruises was not believed to be critical, at least in the beginning, when there were but few observations of the type to be used. For this reason, and considerations of weather, the size of the vessel and its availability, these observations in retrospect are irregularly spaced in time.

Temperature Variations

Procedure. The observational procedure for this investigation was to make bathythermograph observations every half-hour during the transects. A few hydrographic stations were attempted, but the flow of the current is so great as to make the operation very difficult and the results questionable, and they have not been used.

This report has used the partially corrected bathythermograph (BT) traces, as this laboratory does not have facilities for photographing and correcting the slides *en masse*. They will be sent to the Woods Hole Oceanographic Institution (WHOI) for processing. Whenever the BTs made a double trace, the right-hand trace was read.

Listed are the cruises and dates during which the Florida Current was crossed: (for temperature-Depth profiles, GEK vectors, and Temperatures at 100 and 200 meters, see Figures 1 to 16).

T-240	December 22-23, 1952
T-302	January 5-6, 1953
T-304	January 14, 1953
T-307	January 20, 1953
T-311	February 11 and 17, 1953
T-315	March 12-13, 1953
T-320	March 26, 1953
T-323	April 28-29, 1953

Variations in three columns of water. As the observations of the transects increased, it became evident that temperature variations for a column of water existed. In order to study these a chart was made (see Figure 17) consisting of the mean temperatures to 300 feet and to 600 feet, for three columns of water that might show some meaningful pattern. One column was chosen at 80° 01' W, near the Miami shore; a second at 79° 45' W, midstream; and a third at 79° 21' W, near the Bahama Banks. Since all of these cruises were not made in exactly the same latitude, the columns of water under consideration are located with respect to longitude only.

The seasonal change in temperature is recognizable in Figure 17 by the general cooling of the water until the middle of February, and then warming starts to take place. In midstream and along the eastern edge the seasonal change is very clear, but along the western edge it is evident that other strong factors are involved, beclouding the seasonal effect.

Most of the cruises consisted of a crossing of the Current and a return crossing with a delay of a few hours, so that the two transects were made usually within an 18-hour period. Variations in the mean temperatures were noted within this period.

Along the Miami side at 80° 01' W there is indication that the column of water down to at least 300 feet becomes cooler during ebb tide and warms during flood. Towards the middle of the Florida Current at 79° 45' W this same relationship exists, but not so consistently; and along the Bahama side this relationship seems to break down. The daily variation in the mean temperature at the western column is usually greater than that observed in the other two. This might be expected due to the fact that on the west side

of the Current there is a rapid change of temperature vertically as well as horizontally, so that any horizontal or vertical motion of the water would bring in warmer or colder water from a location not very far away. This temperature variation would tend to diminish toward the eastern side of the Current as that water becomes increasingly isothermal, vertically and horizontally. It should also be noted that the time intervals between observations for the column of water at 79° 21' W were much shorter than for the other two columns, a fact which would lessen the chances of noticing any daily variations.

If this warming and cooling is associated with the tides, as it appears to be, then either a whole column of water is moved towards the shore and then back again, or the motion of internal waves associated with the tide may affect the thermal structure vertically. The latter possibility at present seems to be more plausible, since a vertical displacement could more easily produce the large temperature changes observed along this shore-bound region.

The temperature distribution in a vertical section across the Florida Current off Miami, given in Figures 1 to 16, contains another feature of interest. This feature is clearly shown in Figures 1 and 2. The temperature distribution shown in Figure 1 was obtained in the first leg of T-240 cruise. The first BT trace was obtained at 0750 o'clock a few miles off Miami; the remaining traces were obtained at a time interval of one-half hour. The 60°, 65°, and 70° isotherms near the Miami side are seen, in Figure 1, to be in the depth interval of 300-400 feet. Figure 2 shows the temperature distribution found during the return leg of the T-240 cruise; the two BT traces nearest to the Miami shore were obtained at 1405 and 1530 o'clock the next day. The corresponding 60°, 65°, and 70° F isotherms are now seen to be in the depth

interval of 200-300 feet. The isotherms have risen 100 feet. This shoaling feature of the isotherms, expressed in terms of the cooling of the water column, is summarized in the top frame in Figure 20 for all the cruises. In addition to the shoaling feature, the isotherms tend to pack together when they rise; this is readily seen, for example, in Figures 3 and 4, and has been noted during a 48-hour anchor station in the Current during May.

The period and cause of this recurring phenomenon can not be determined from existing data. Parr (1937) suggested an east to west transverse movement of pockets of high salinity water along Sigma-T surfaces. If this suggestion applies, then the slope of the appropriate Sigma-T surfaces in the present data must be greater than that of the isotherms. This can be seen in Figures 9 and 10, for if the water column near the Miami shore were to be colder and to have a stronger temperature gradient at the 300-foot depth, the pocket of water must come from a depth of 650 feet or more near the Cat Cay side. Unfortunately, no salinity data are available to check this.

Figures 25 to 29 show the BT traces of five transects across the Florida Current. These five were selected because a complete GEK record for the same period is also available, making comparison possible. In reading these traces the Miami side is on the left, and the Bahama Banks on the right.

An interesting phenomenon to note is that each section of the Current, transversewise, produces a BT trace that is quite peculiar to itself. In other words, a trace made on the west side is very different from one made on the east side. The depth to the first strong thermocline deepens from west to east, and the trace gradually straightens out. Not far from the Bahamian side the traces show more small irregularities and show slight temperature

inversions. Near this region also the depths to the first strong thermocline show some irregularities. As will be noted in Figure 14 this region was a transitional area between the main current and a counter current close to shore. It appears that at the area of highest surface velocity the depth to the first strong temperature change increases and then decreases once that area is past. Another phenomenon that has been observed in this set of BT traces is that the traces west of the current axis are apt to show more than one sharply defined thermocline, while to the east of the axis the traces show less well defined thermoclines, and often only one.

Almost no temperature inversions on the traces have been noted on the west side of the Current. This fact, however, may indicate that usually little or no cold water is flowing southward along the west side of the Current. Temperature inversions along the left approaches of the Gulf Stream, east of Cape Hatteras, are almost always noted.

The temperature-depth traces for a column of water change with time, as may be seen by comparing Figures 25 to 29. The greatest change is that associated with the depth to the first sharp thermocline. This change in depth may be a seasonal change, being deep in the winter and shoaling with spring. The depth may depend upon the water transport, deepening with increased transport, which in turn may be associated with the seasons. Von Arx (personal communication) has suggested that the tidal cycle in the Gulf of Mexico may influence transport, temperature, and salinity in this region. The angle of the trace below the thermocline does not change appreciably except that in December (Figure 25) the temperature change with depth was much greater than during the other months.

It is hoped that with a set of BT traces that cover a complete year

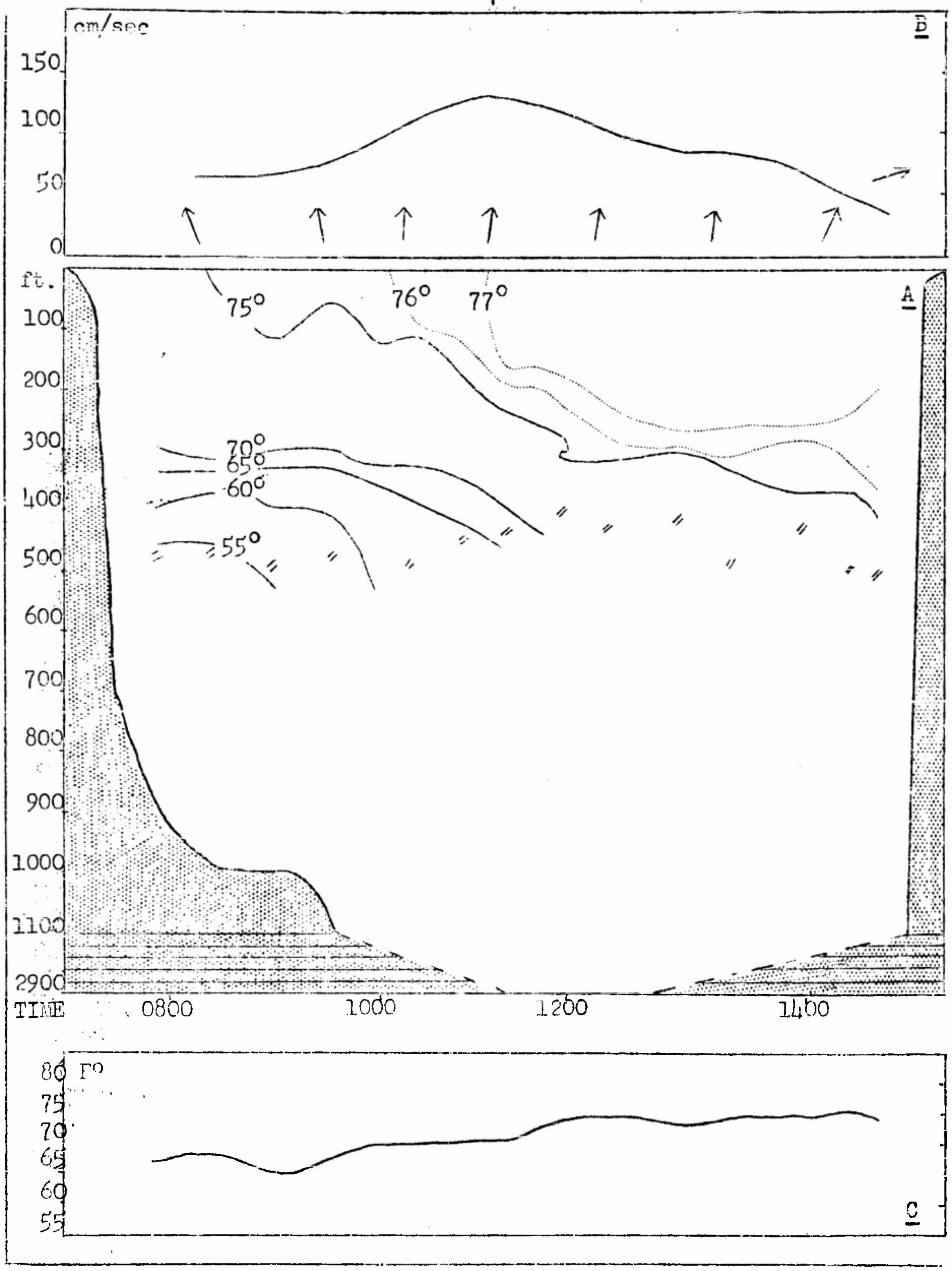


Figure 1. A TEMPERATURE-DEPTH PROFILE B GEK VECTORS
C TEMPERATURE AT 300 ~~METERS~~ FT.
Data from Cruise T-240 Miami to Cat Cay December 22, 1952.

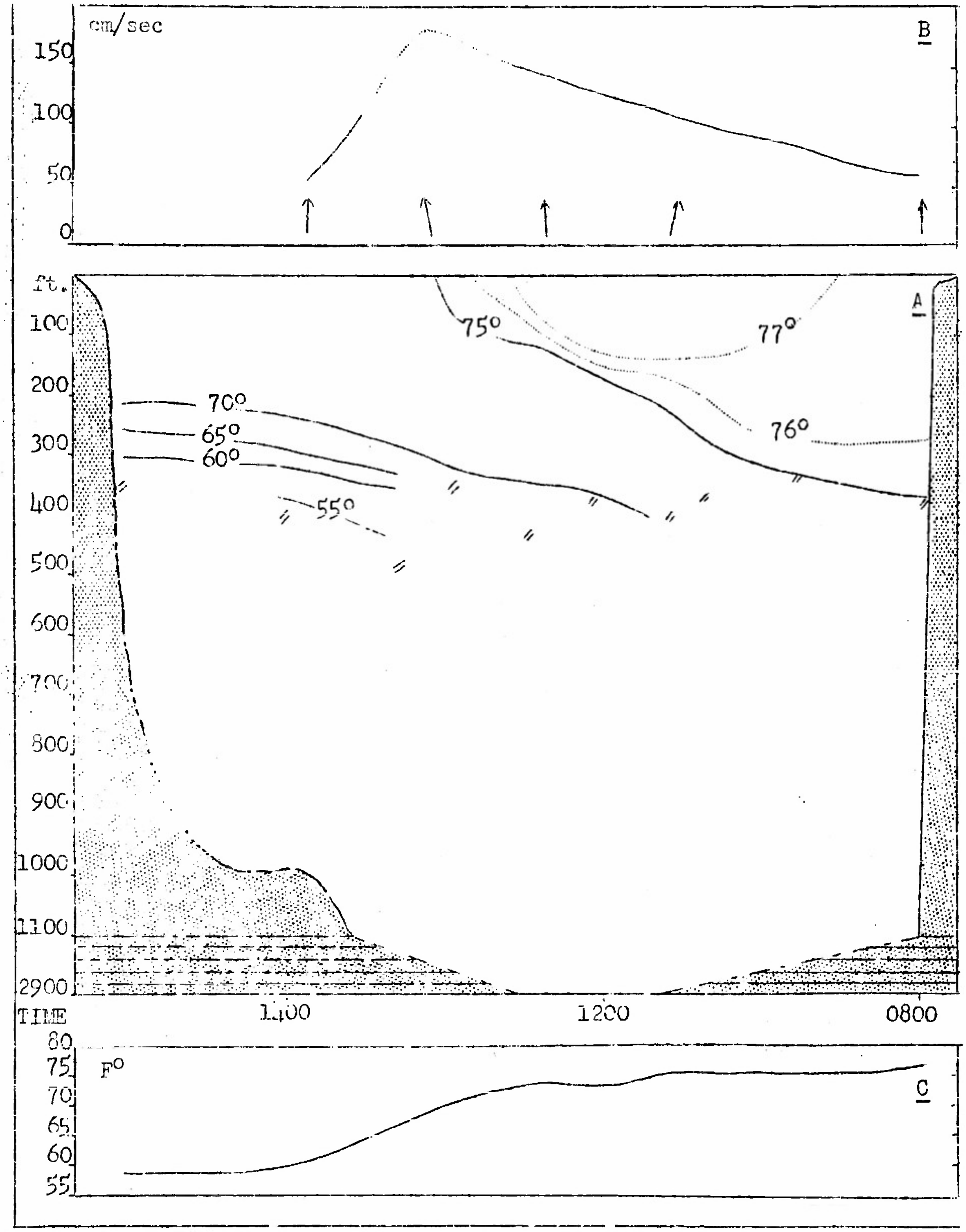


Figure 2. A TEMPERATURE-DEPTH PROFILE B GEK VECTORS
C TEMPERATURE AT 300 ~~METERS~~ FT.
Data from Cruise T-240 Cat Cay to Miami December 23, 1952.

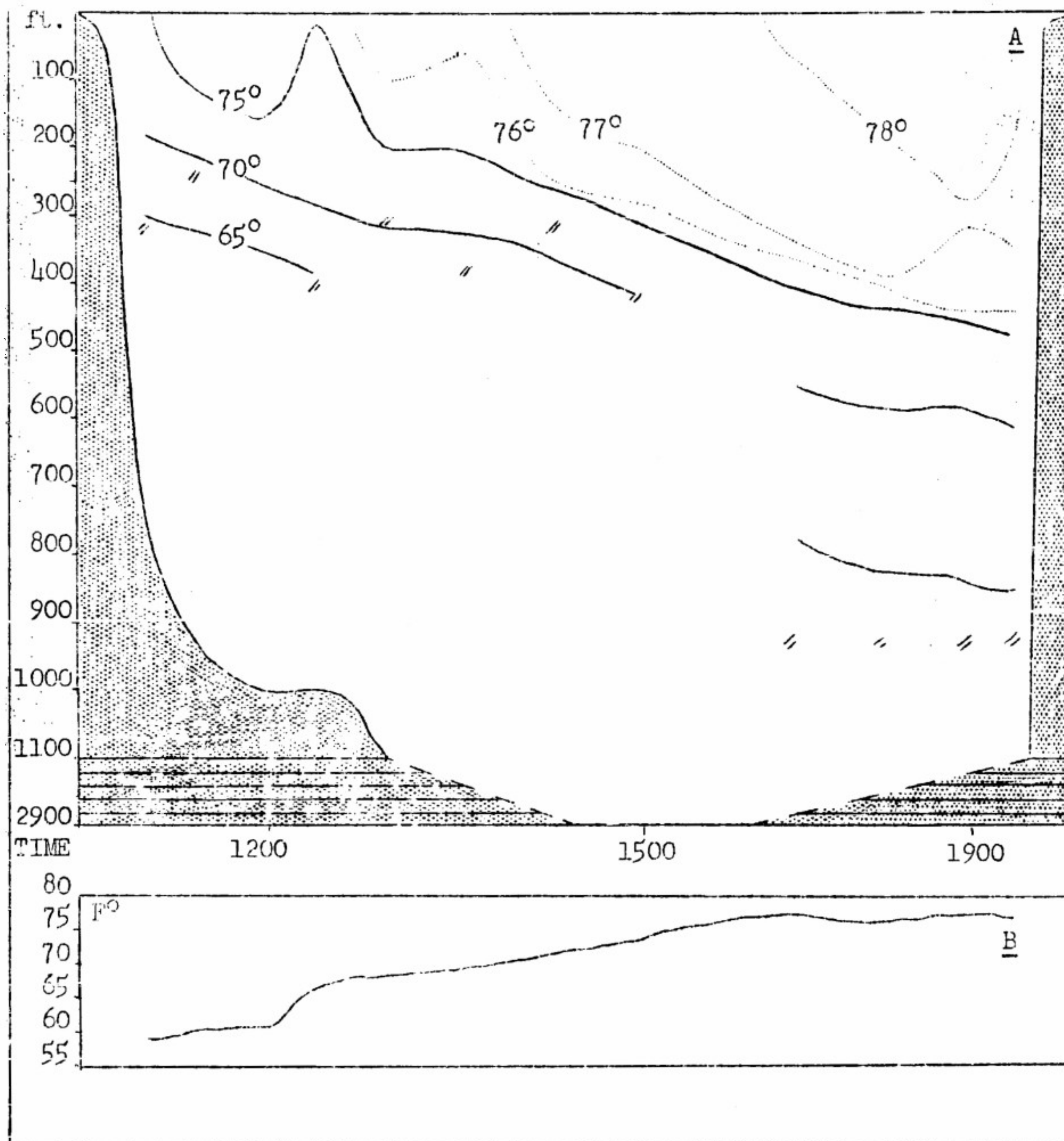


Figure 3. A TEMPERATURE-DEPTH PROFILE
B TEMPERATURE AT 100 METERS
Data from Cruise T-302 Miami to Cat Cay January 5, 1953.

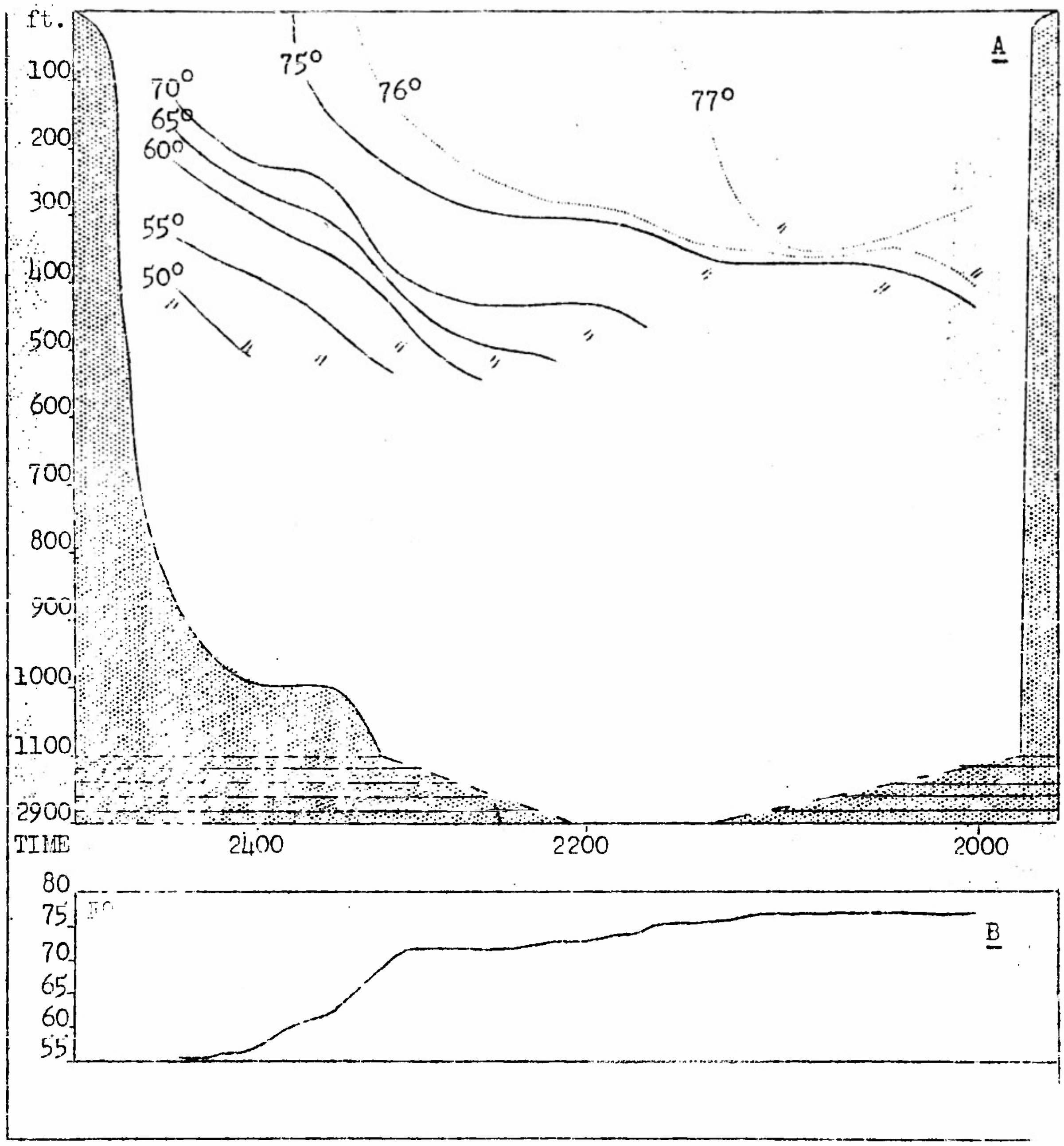


Figure 4. A TEMPERATURE-DEPTH PROFILE
B TEMPERATURE AT 100 METERS
Data from Cruise T-302 Cat Cay to Miami January 5, 1953.

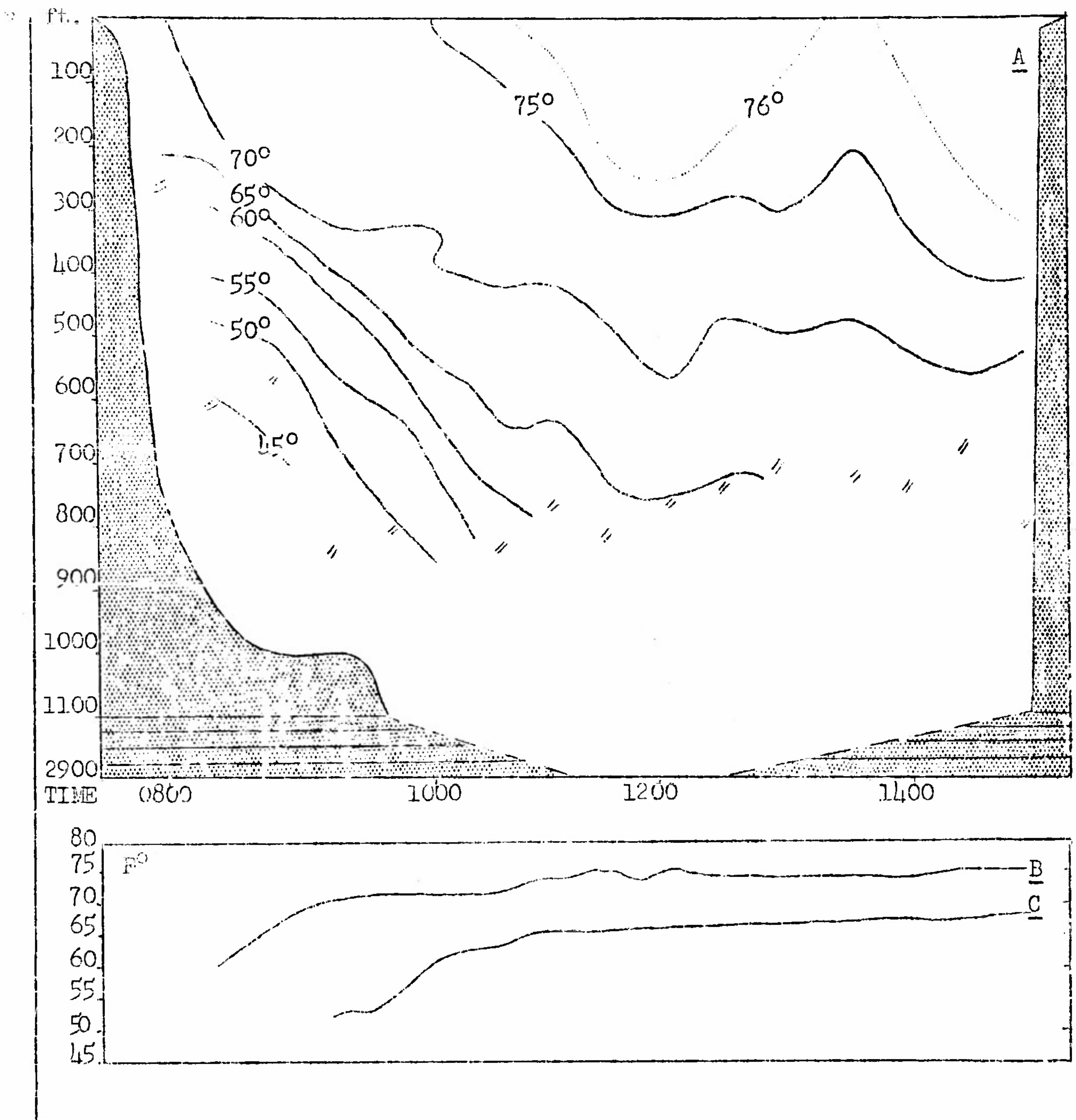


Figure 5. A TEMPERATURE-DEPTH PROFILE
B&C TEMPERATURES AT 305 AND 625 FEET
Data from Cruise T-304 Miami to Cat Cay January 4, 1953.

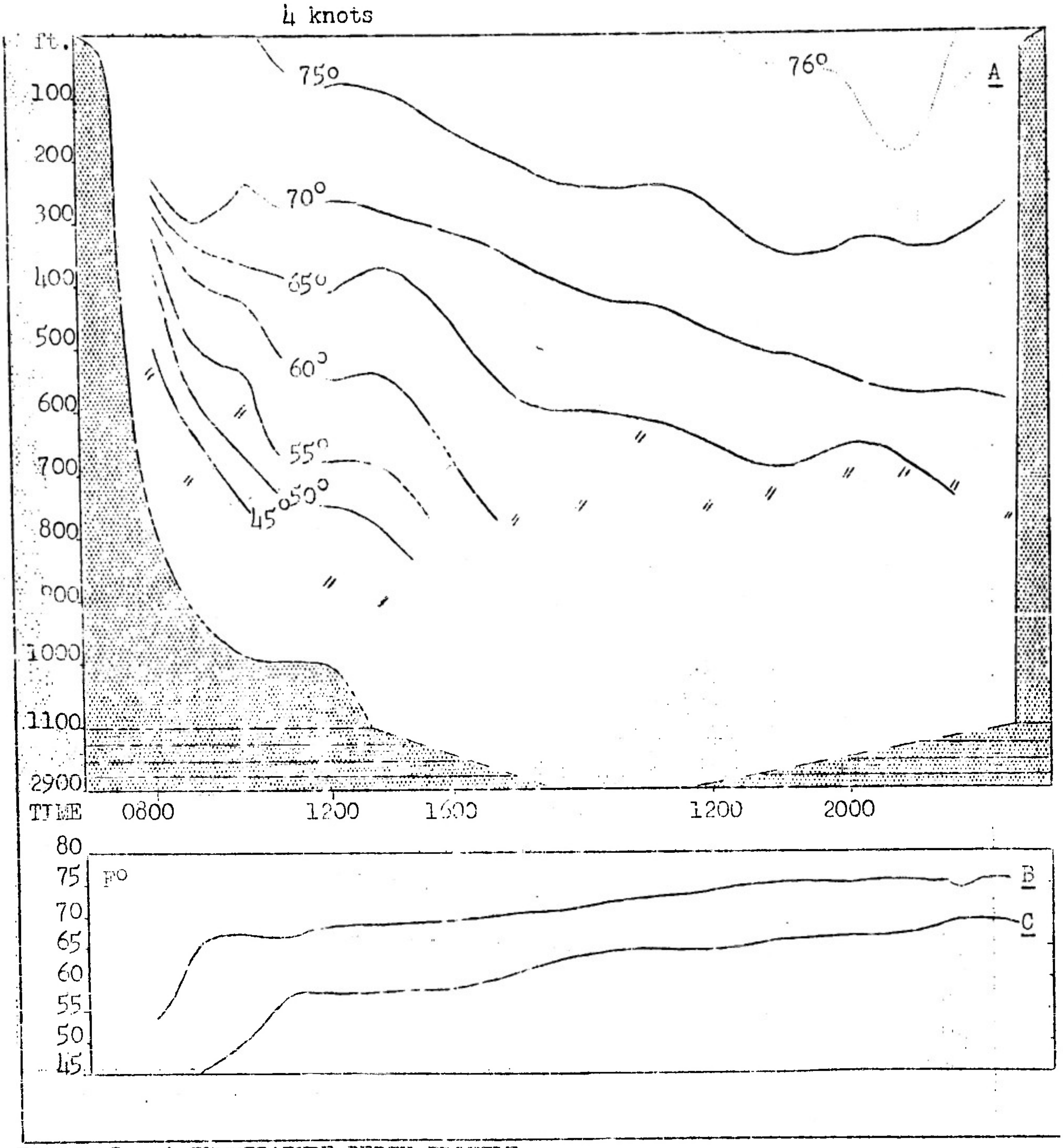


Figure 7. A TEMPERATURE-DEPTH PROFILE
B&C TEMPERATURES AT 100 AND 200 METERS
Data from Cruise T-307 Miami to N. Bimini January 20, 1953.

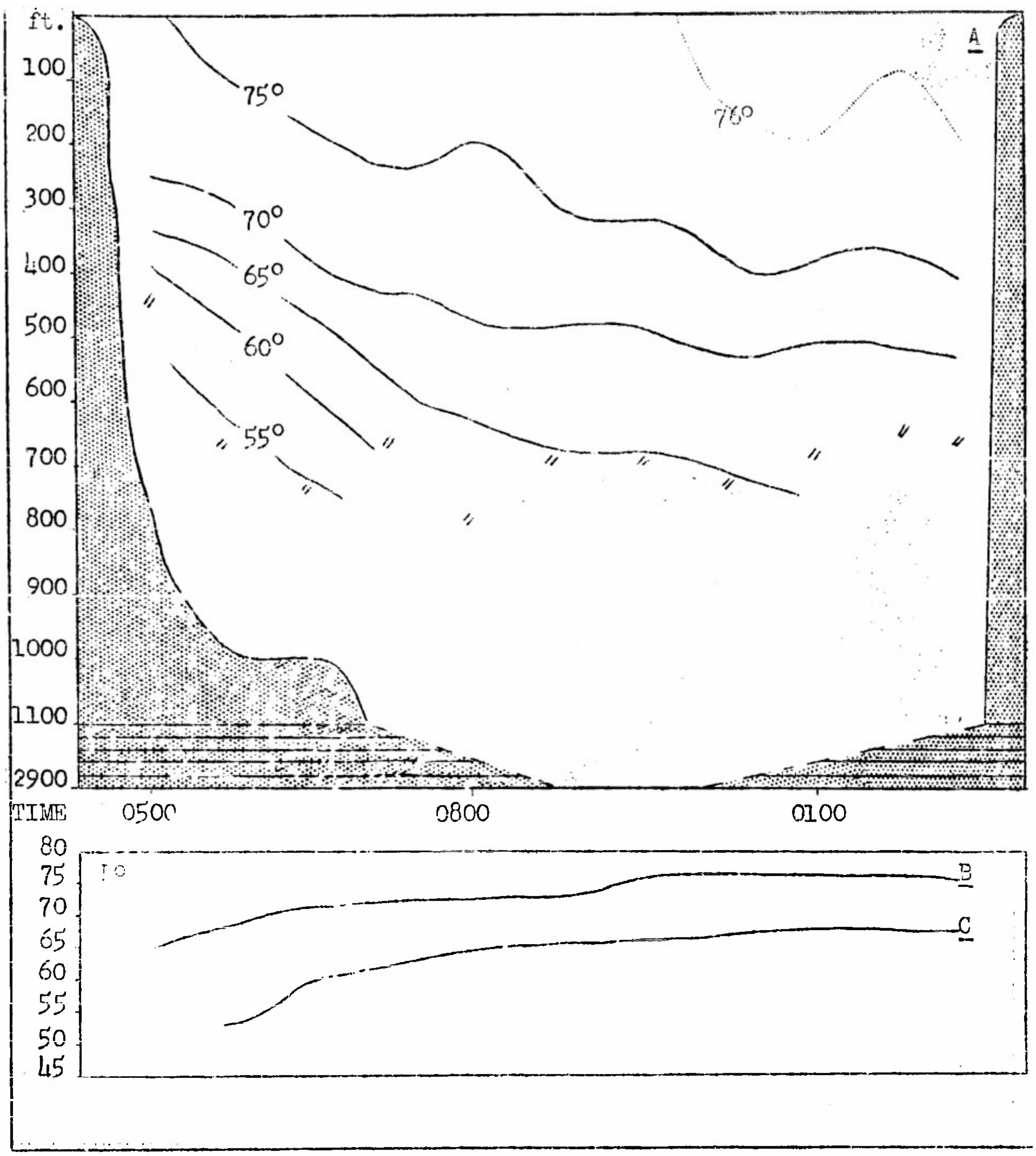


Figure 8. A TEMPERATURE-DEPTH PROFILE
B&C TEMPERATURES AT 100 AND METERS
Data from Cruise T-307 N. Bimini to Miami January 21, 1953.

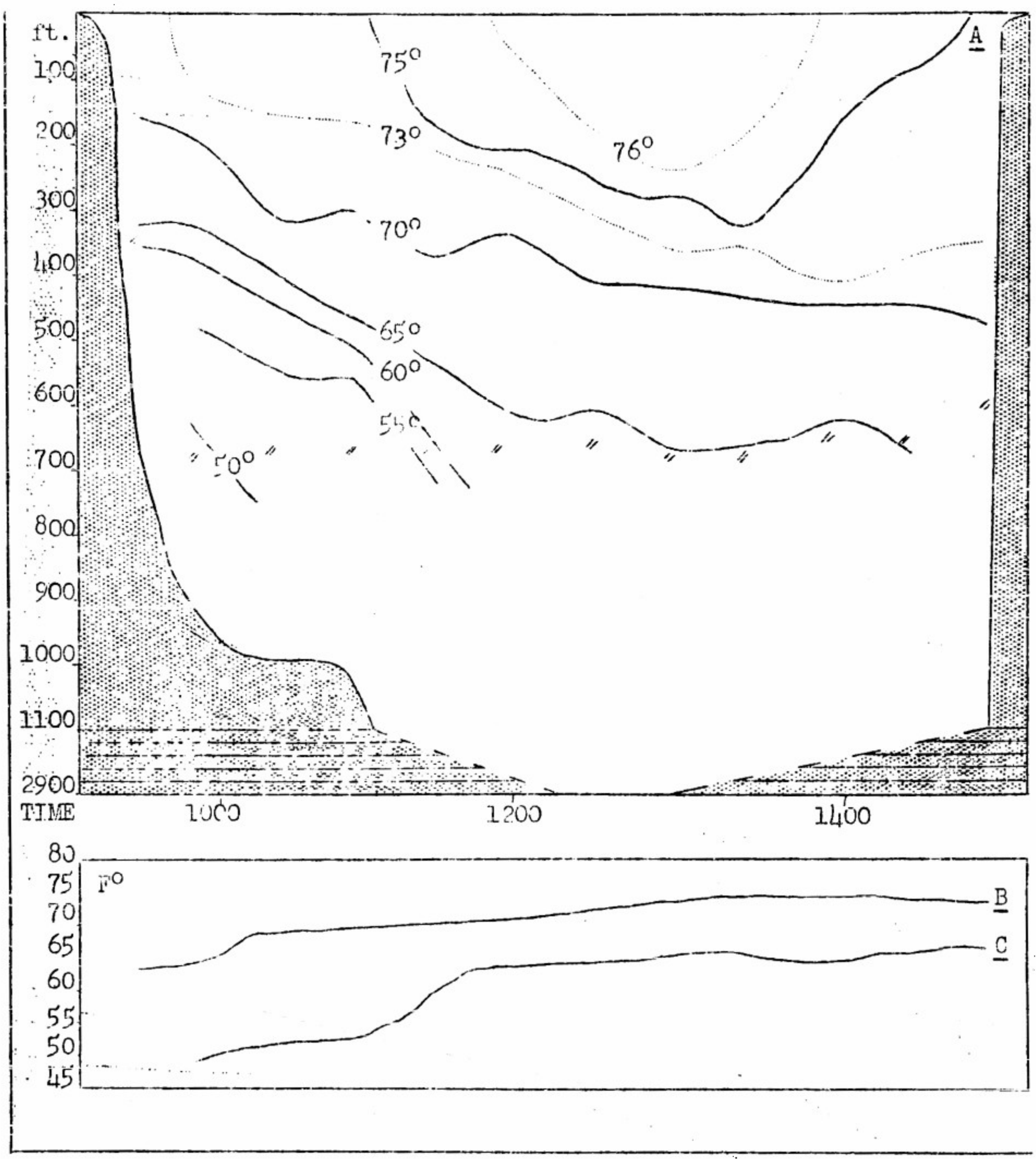


Figure 9. A TEMPERATURE DEPTH-PROFILE
B&C TEMPERATURES AT 100 AND 200 METERS
Data from Cruise T-311 Miami to Cat Cay February 11, 1953.

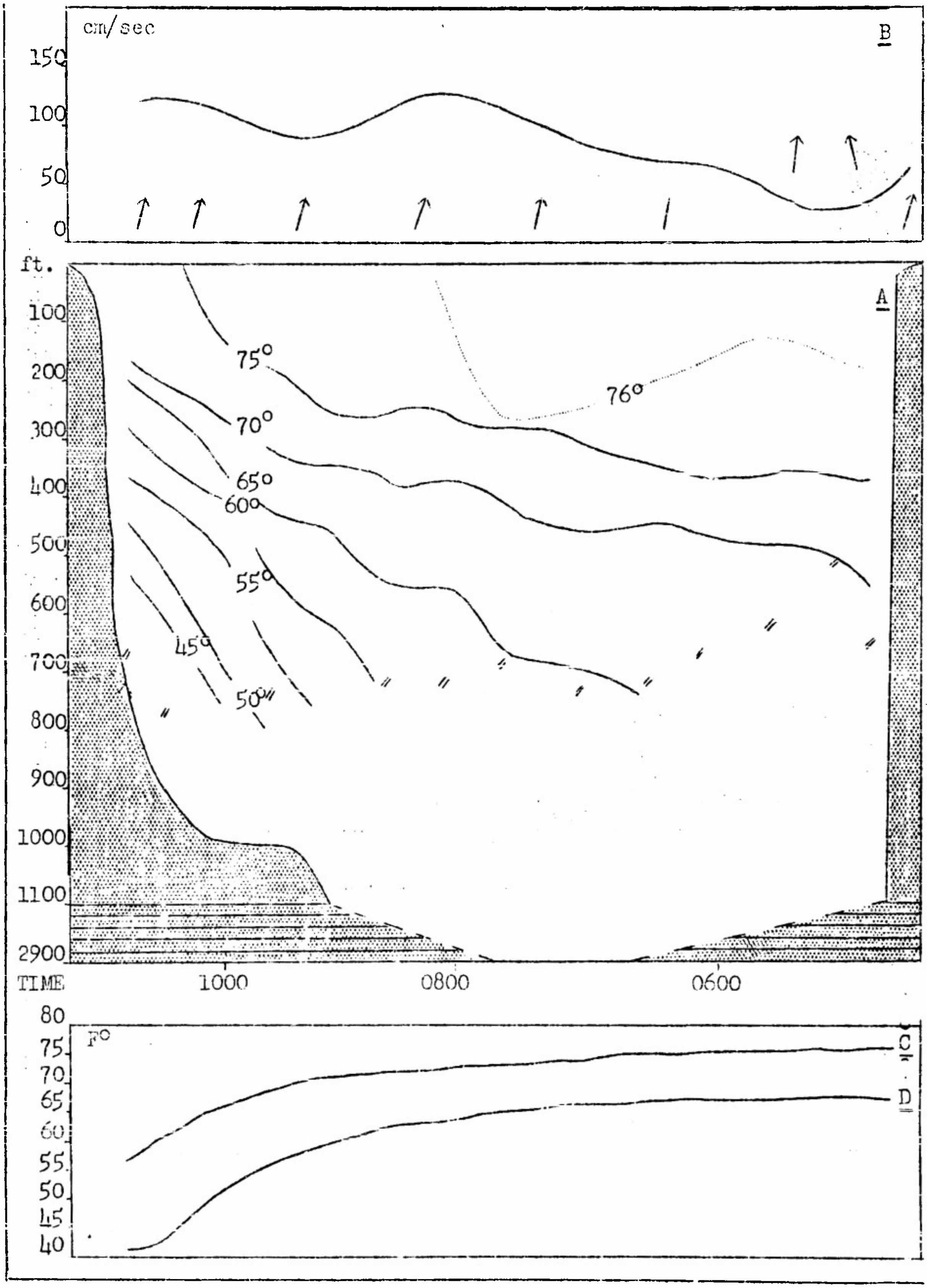


Figure 10. A TEMPERATURE-DEPTH PROFILE B GEK VECTORS
C&D TEMPERATURES AT 100 AND 200 METERS
Data from Cruise T-311 N. Rock to Miami February 17, 1953.

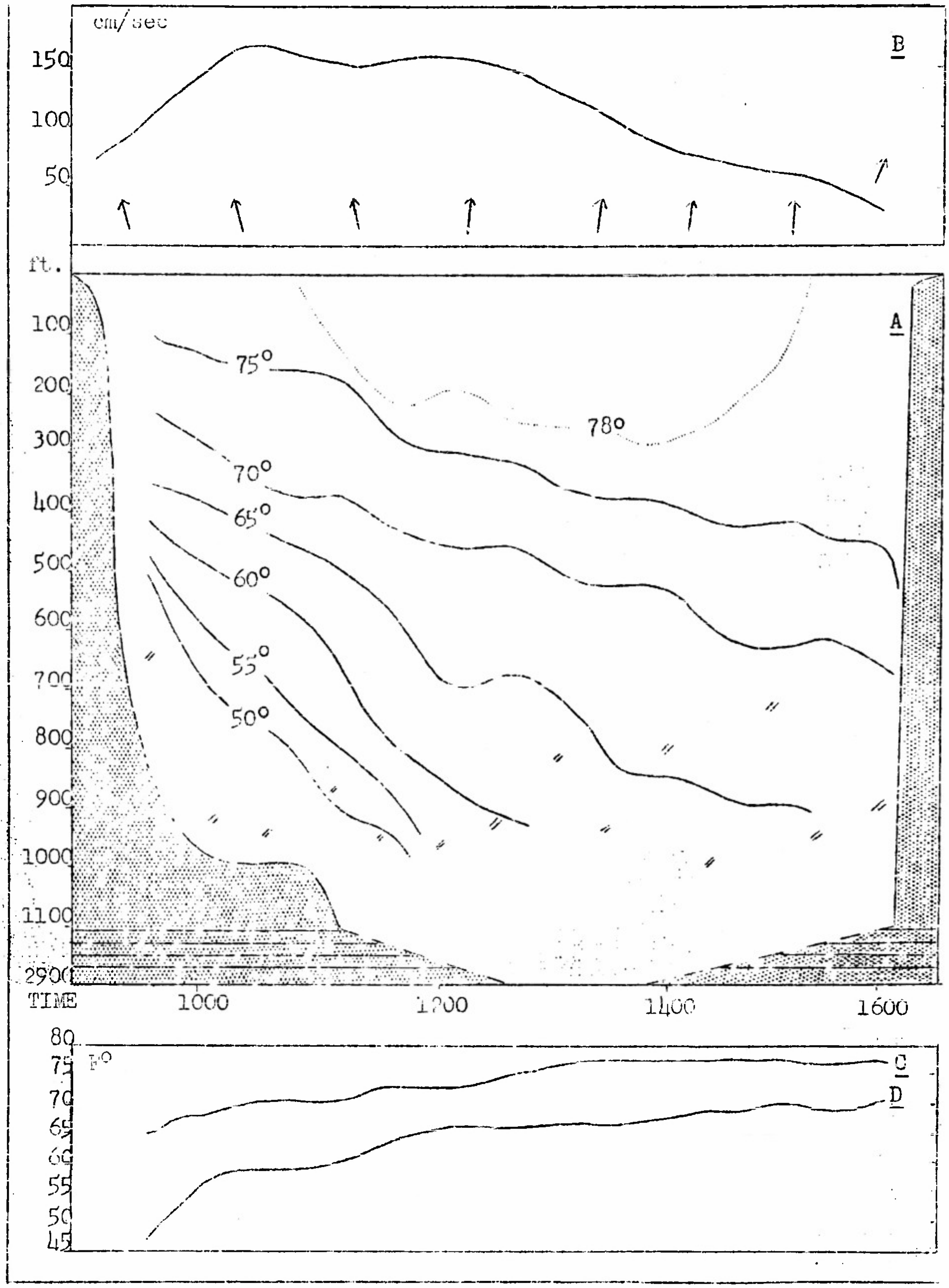


Figure 11. A TEMPERATURE-DEPTH PROFILE B GEK VECTORS
C&D TEMPERATURES AT 100 AND 200 METERS
Data from Cruise T-315 Miami to Cat Cay March 12, 1953.

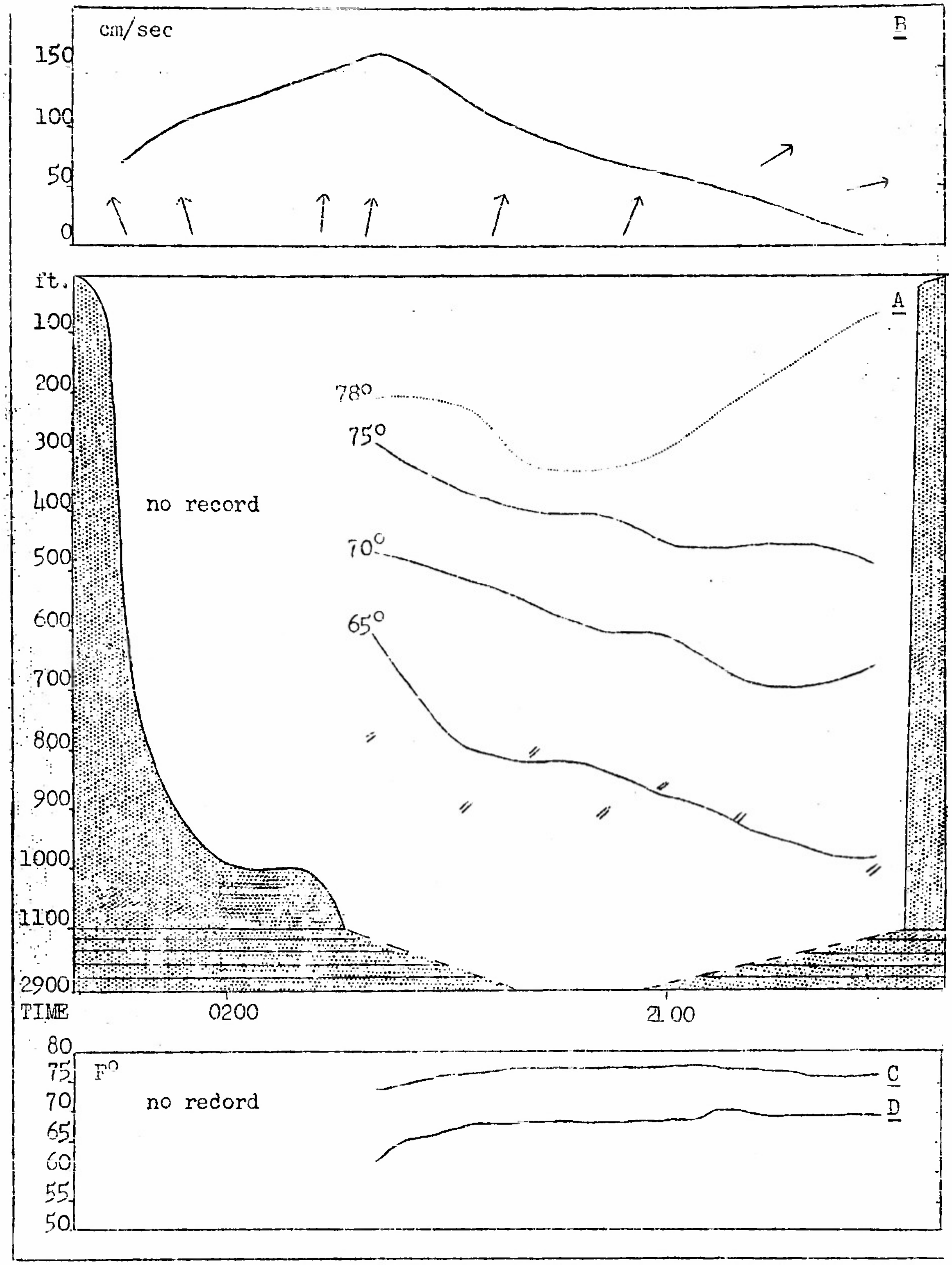


Figure 12. A TEMPERATURE-DEPTH PROFILE B GEK VECTORS
C&D TEMPERATURES AT 100 AND 200 METERS
Data from Cruise T-315 Cat Cay to Miami March 12, 1953.

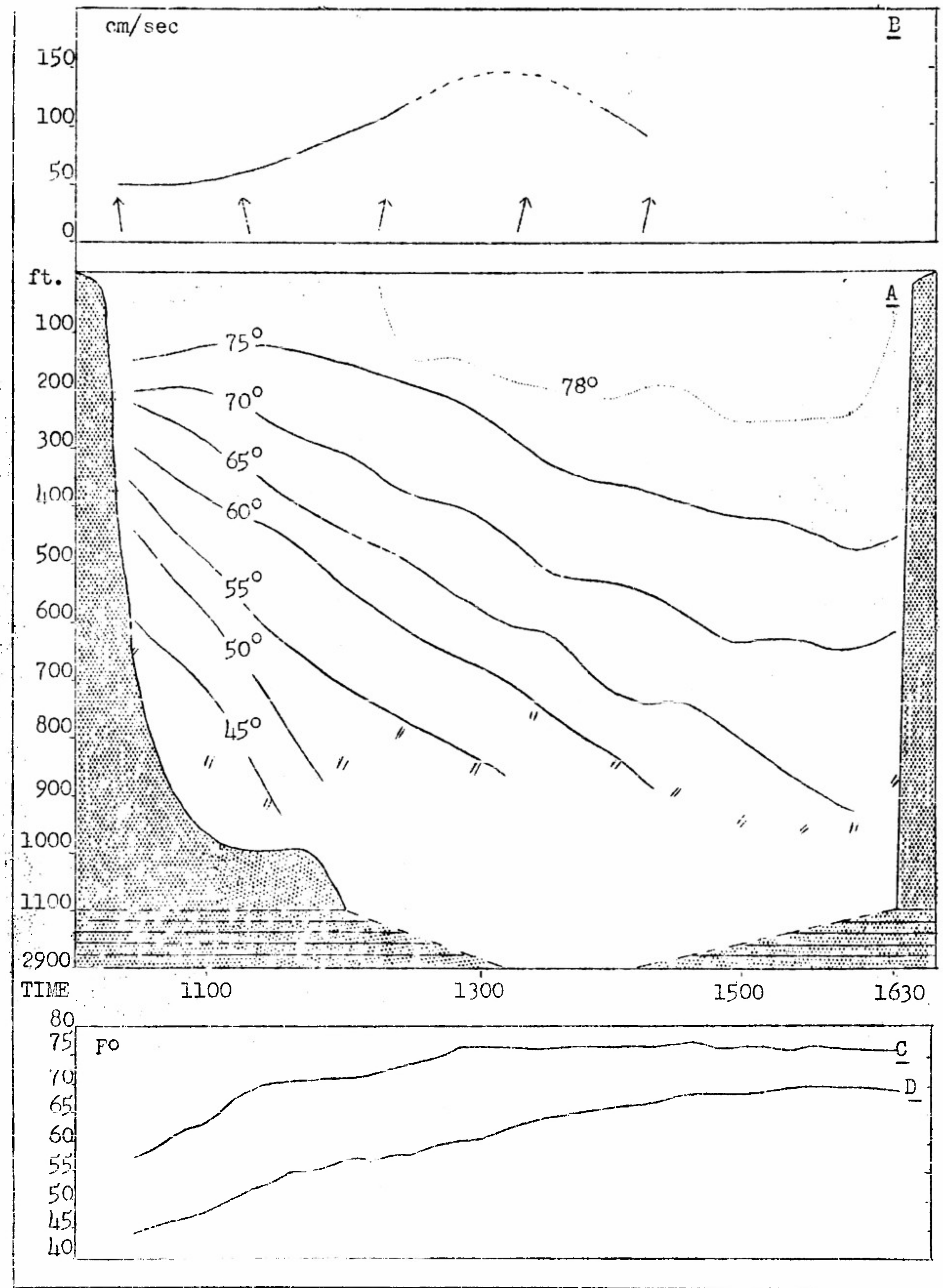


Figure 13. A TEMPERATURE-DEPTH PROFILE B GEK VECTORS
C&D TEMPERATURES AT 100 AND 200 METERS
Data from Cruise T-320 Miami to Cat Cay March 26, 1953.

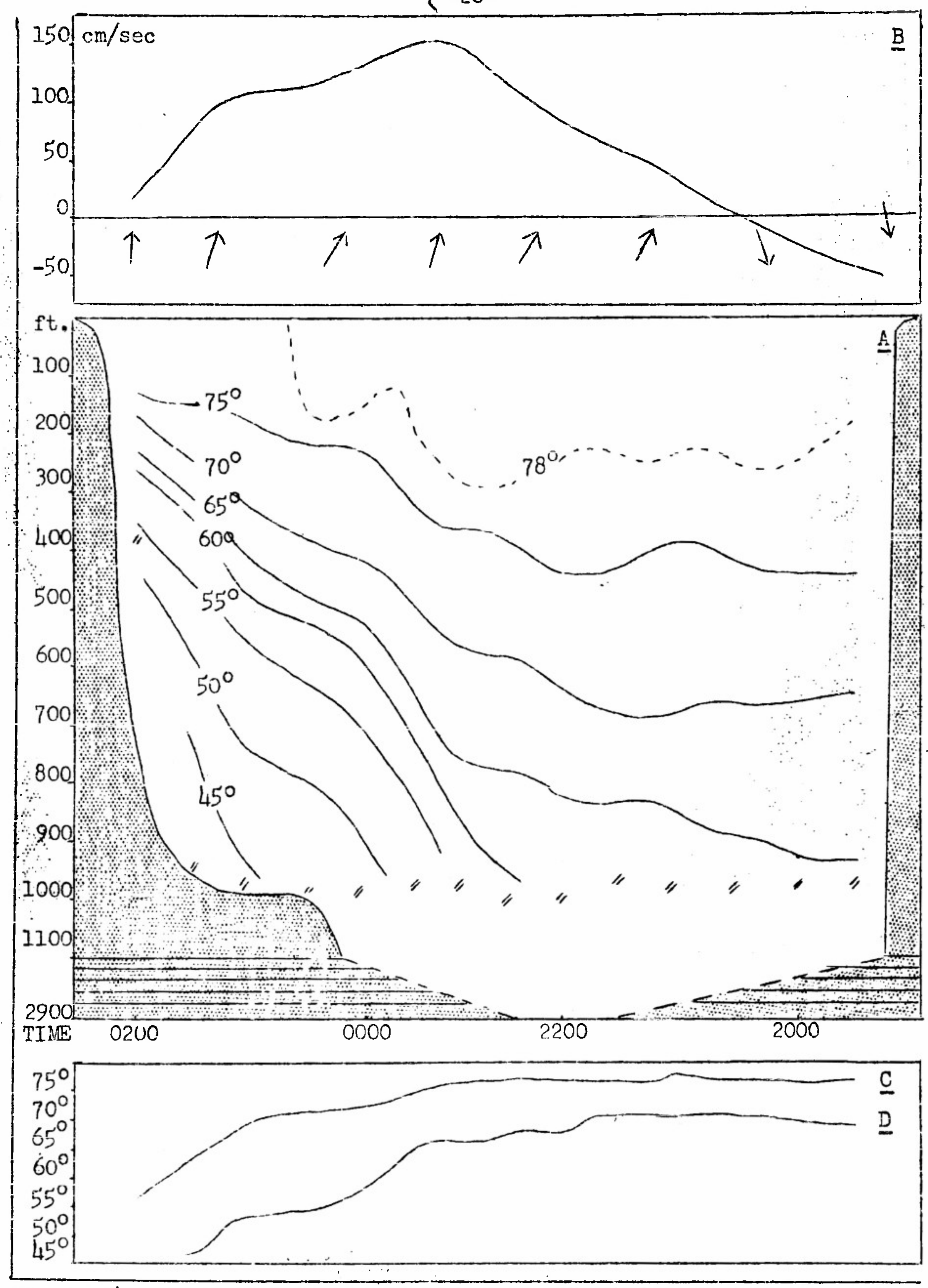


Figure 14. A TEMPERATURE-DEPTH PROFILE B GEK CURRENT PROFILE
C&D TEMPERATURES AT 100 AND 200 METERS
Data from Cruise T-320 Cat Cay to Miami March 26, 1953.

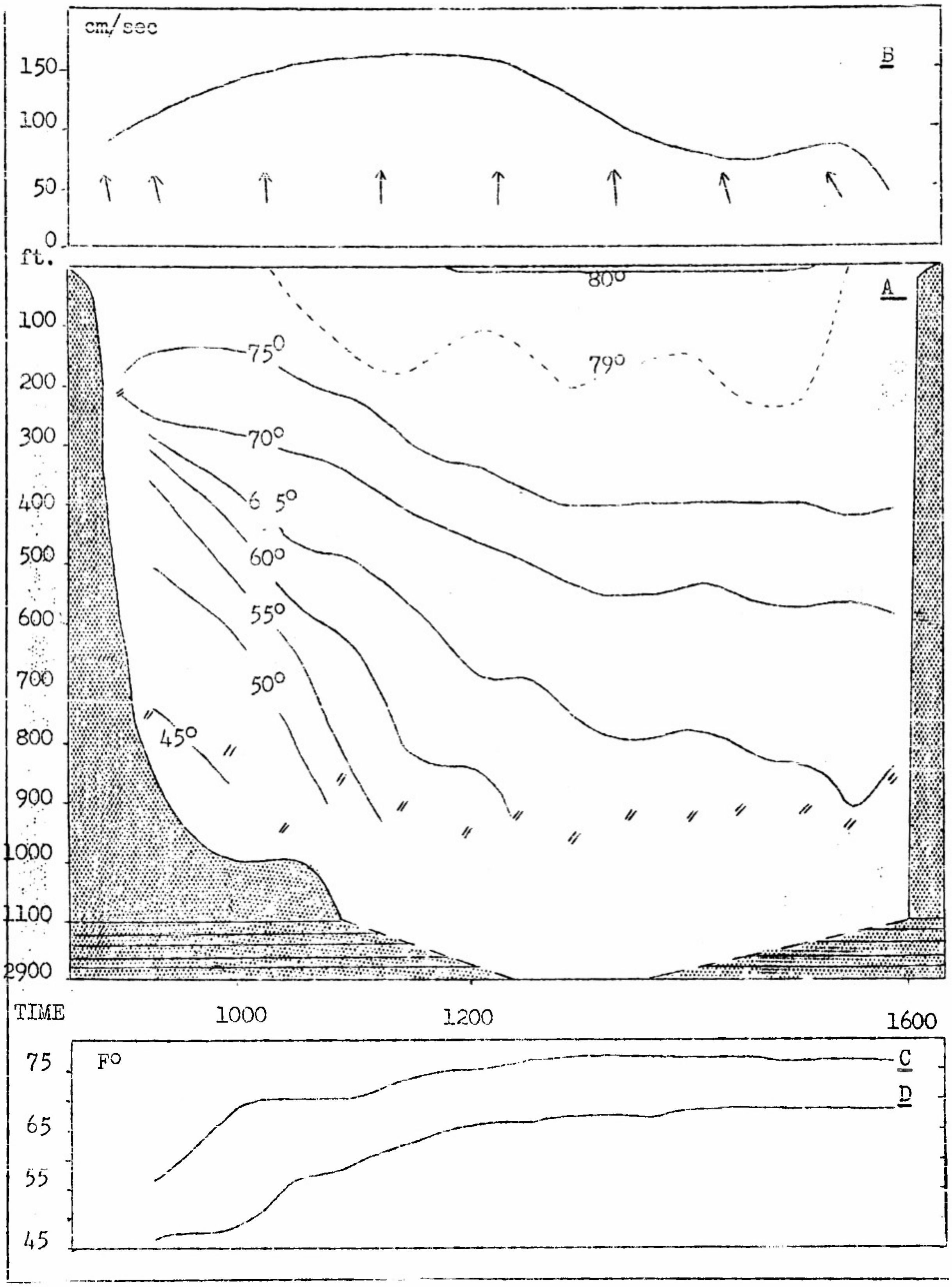


Figure 15. A TEMPERATURE-DEPTH PROFILE B GEK VECTORS
C & D TEMPERATURES AT 100 AND 200 METERS
Data from Cruise T-323 Miami to Cat Cay April 28, 1953.

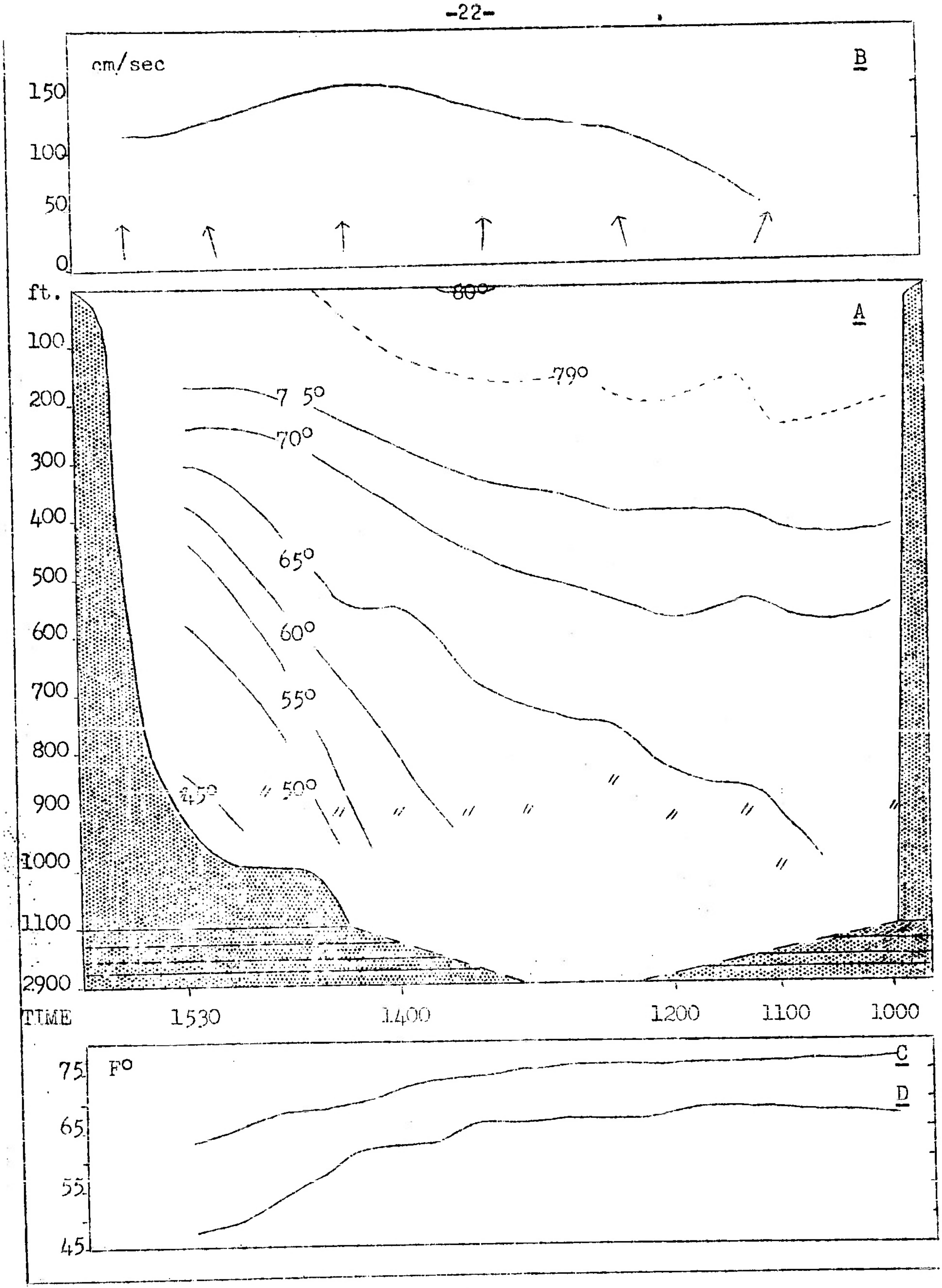


Figure 16. A TEMPERATURE-DEPTH PROFILE B GEK VECTORS
C & D TEMPERATURES TO 100 AND 200 METERS
Data from Cruise T-323 Cat Cay to Miami April 29, 1953.

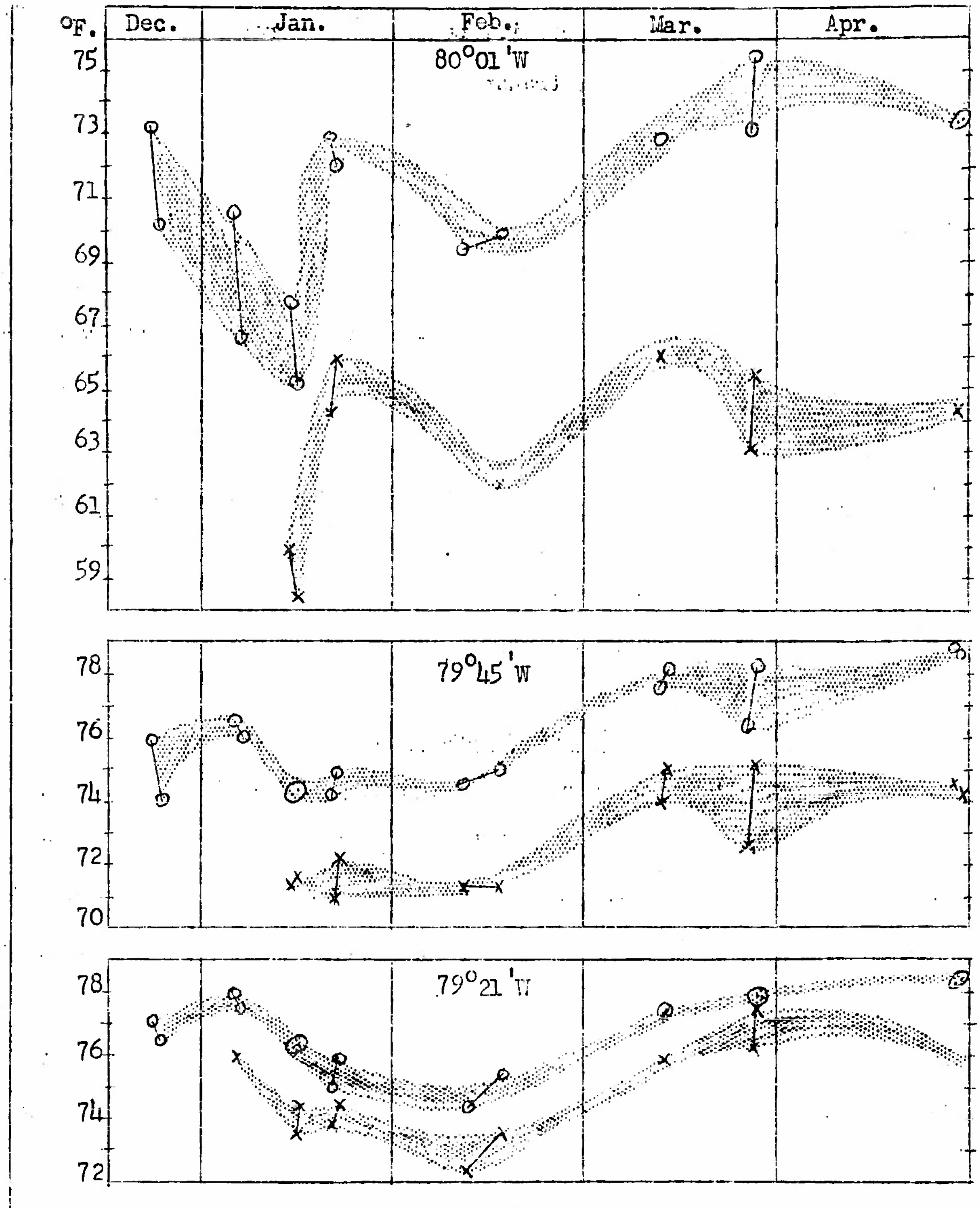


Figure 17. MEAN TEMPERATURES TO 300 AND 600 FEET FOR COLUMNS OF WATER AT 80°-01'W, 79°-45'W and 79°-21'W. O = 300ft. X = 600ft.

and are well spaced in time, one will be able to correlate their configurations with current velocities, transport, the seasons, changing water masses, and the general wind pattern of the Trades.

Future plans. Without doubt there are other factors involved to produce thermal variations in this body of water. The procedure of making transects across the Florida Current has made it difficult to obtain a picture of a column of water with respect to time. Other considerations were involved when this procedure was adopted. For this reason it is planned to hold a position for 24 hours or more while observations are being made. A series of such stations will be valuable in describing thermal variations and in ascribing causal factors to them. An effort along this line has been started jointly by the Marine Laboratory of the University of Miami, the WHOI, and the Fish and Wildlife Service.

Velocity Structure

Procedure. The GEK was used as frequently as possible in the Florida Current Survey. From December 22, 1952 to April 29, 1953, 75 GEK fixes were made in the general area between Miami and Cat Cay-Bimini. Most of these fixes were made during complete transects across the Current, and a few were made along the western edge within sightof land, so that GEK readings might be compared with velocities indicated by drift buoys. That work will be described in detail below. Eight satisfactory transects were made in the following manner.

The ship's heading was determined by the average surface velocity to be expected (three knots) between Miami and Cat Cay. During the outbound crossing a course of 127° T was steered for the complete crossing. With an

average speed of between six and one-half and seven and one-half knots, the time for crossing was usually about seven hours. The general procedure was to make a GEK fix as close as possible to the edge of the banks on each side of the Straits with fixes spaced every hour in between. The fix was executed by turning 90° to the right from base course and steering that heading for three minutes. A 180° turn to the right was next executed, and that heading was followed for three minutes. The base course was then resumed. This type of maneuver should bring the vessel back to its original position except for the distance set by the current.

Accurate positions were taken at the first and last GEK fix, and bearings were taken while in sight of land. All other positions have been derived from dead reckoning. (Loran does not operate well in this area.) It is assumed that the electrode pair is well matched (made at WHOI) and that it is not polarized significantly; in effect the GEK reading is assumed to be correct. Then there remain two primary sources of error - errors due to steering and windage. The steering error is taken to be half a nautical mile either way. (For future consideration this amount affects the computed transport by 8 per cent at the most.) Table 1 below gives the average wind speed and direction during crossings of the Straits when the GEK was being used.

TABLE 1

Cruise	Average Wind Direction	Average Wind Speed (Beaufort Scale)
T-240A	300°	3
T-311B	330°	(First half of leg) 1 (Last half of leg) 3 to 4
T-315A	150°	4
T-320B	010°	3
T-323A	110°	2

Transport determination. An attempt has been made to determine transports of the Florida Current in the manner evolved by Malkus and Stern (1952). Stated simply the mean current velocity (MCV) for a particular column of water is the difference between actual surface velocity (as determined by the set of the vessel) and the GEK reading.

Mean Current Velocity = Actual Set - GEK Velocity
(uncorrected for K)

Total Transport = Mean Current Velocity x Area of Cross Section

This determination of transport has been modified to fit our purpose. Due to the fact that no accurate positions could be established between the first and last GEK observations, it was impossible to determine the MCV or the K factor for each GEK fix. Had that been possible the MCV could have been established at several columns of water across the Current. It was feasible, however, to determine the total set for each transect of the Current and then compare that with the accumulated GEK sets or velocities. In this way a MCV from top to bottom and across the whole Current was established. For a diagramatic representation of this procedure, see Figure 18.

There are two important assumptions that have to be made in computing the transport by this modified method. The first is that the MCV for the complete transect is the same as the average of the several MCVs at each GEK operation. The second assumption is that the cross sectional area of the Current to be multiplied by the MCV is approximately 43 million square meters. This area was determined from Chart 1112 (U.S. Coast and Geodetic Survey) between Miami and Bimini. At present it is impossible to estimate the cross sectional area of the moving water. Table 2 summarizes the results of the six GEK transects.

TABLE 2

Cruise	Date	Mean K	Mean Current Velocity cm/sec	Transport $10^6 m^3/sec$
T-240A	December 22-23 1952	2.2	94	40.5
T-311B	February 17 1953	2.2	101	43.5
T-313B	February 27 1953	1.5	49	21.04
T-315A	March 12 1953	1.6	62	26.6
T-320B	March 26 1953	1.8	57	24.5
T-323A	April 28 1953	1.4	53.5	23.0

The transport values for the last four listed cruises are close to the conventionally accepted value of 26 x $10^6 m^3/sec$ (Sverdrup, et. al. 1946 p. 672). Those for cruises T-240 and T-311 are much larger. Because no previous published computations have shown such high figures, it is necessary that they be "justified". During the T-240A cruise the wind directions were mostly north with the remainder from the northwest, and during cruise T-311 the winds were from the same quadrant with higher speeds during the latter part of the transect. (See Table 1.) It would appear that any error due to windage would decrease the observed set with respect to the actual set for these two cruises, and so diminish the transport value. Hence their larger transport values are apparently "real" as far as windage is concerned. G. Wertheim's (personal communication) study of the Florida Current transport using the Western Union Key West-Havana cable indicated that the uncalibrated electric potential readings have fluctuated by a

factor of two; this may or may not mean that the Florida Current transport fluctuates by a factor of two, but the impression is that it does have a large short term fluctuation. W. von Arx (personal communication) thinks such large fluctuation is due to the diurnal tide in the Gulf of Mexico, and he is currently studying certain of its aspects. Finally, the correlation between the water prism above the observed thermocline and the average K factor may be invoked (see pages 11 to 13) in support of the computed transport, for the same factors which enter in the transport also define the magnitude of the K factor, namely,

$$K = \frac{\text{actual set}}{\text{GEK set}}$$

Transports and depth of first strong thermocline. Stommel (1948) has shown that, for a non-conducting bottom, the K factor (a non-dimensional number by which the observed GEK signal must be multiplied to yield the corrected current speed) is dependent upon the thickness of the moving layer relative to the thickness of the resting subjacent layer. In the absence of actual measurement of the depth of no motion, and as a first approximation, the depth of the observed thermocline was used. The plausibility of this line of thought is based on the physical fact that at the thermocline, where, in general, the rapid decrease in temperature with depth effects rapid vertical change in horizontal pressure gradient and stress force, there is large vertical shear in current speed provided the salinity increases with depth or decreases but slightly. But there are no *a priori* reasons to insure that the approximation is workable; for many processes work to displace the thermocline. In the first place, the thermocline is a discontinuity surface; as such its slope is governed, at

least partially, by the horizontal shear of current across the surface as expressed in Margules' equation for frontal slope. In the second place, the thermocline, being the lower boundary of the mixed layer, changes its depth as the strength of convection and wind-stirring vary. And lastly, other processes in the ocean, such as internal waves, convergence, and divergence, will add further complications. To minimize some of these difficulties, the observed thermocline depths were not used directly. Rather, the size of the water prism above the observed thermocline was assumed to have the characteristics of the total moving layer as far as the K factor is concerned. As will be seen later, in spite of these complicating processes and crude approximations, the assumption appears to be workable. Nevertheless, the possibility of fortuitous coincidence cannot be ruled out. Studies of thermocline depth, such as Patullo's, have shown the depth to vary seasonally - generally attaining its greatest depth in January or February and beginning to shoal as spring approaches. More data are needed before a sound conclusion can be reached.

Figures 25 to 29 are reproductions of the BT traces corresponding to the GEK transects. The thermocline, here defined as the depth at which the first "strong" temperature gradient begins, is readily found in the sections for cruises T-311, T-315, T-320, and T-323. It is less obvious for cruise T-240, but comparisons with temperature-depth traces of other cruises show that the thermocline shown as the curve B-A (Figure 25) is a reasonable one. (BT traces for T-240 extend only to about 400 feet, thus in the comparison, the portion of BT traces deeper than 450 feet in other cruises should be disregarded.) These thermocline depths are replotted in their true relative geographical positions in Figures 22 to 24. The cross-sectional area of the

moving water prism above the thermocline and between 79° 22.5' and 80° 02.5' for all cruises were then found by planimetry. The increase or decrease of the water prism appears to depend primarily on the greater deepening of the thermocline depth, near the Miami side, while near the Cat Cay side, it may deepen, shoal, or remain unchanged. Table 3 below summarizes the sizes of the water prisms above the thermoclines and their corresponding K factor and computed transport values.

TABLE 3

Cruise	Date	Average K Factor	Cross-Sectional Area of Water Prism Above the Thermocline ($10^6 ft^2$)	Transport Through Florida Straits ($10^6 m^3/s$)
T-240A	December 22-23 1952	2.2	5.9	40.5
T-311B	February 17 1953	2.2	5.9	43.5
T-313B	February 27 1953	1.5	no record	21.04
T-315A	March 12 1953	1.6	(large) 5.0 (small) 4.8	26.6
T-320B	March 26 1953	1.8	5.1	24.5
T-323A	April 28-29 1953	1.4	3.6	23.0

It is seen that the correlation between the average K factor and the cross-sectional area of the water prism above the thermocline is very encouraging.

Thermocline and velocity axis. Figures 22 to 24 of the thermocline depths reveal another feature of great interest. For cruises T-315, T-320, and T-323, the speed axis of the Florida Current is near a dip in the

thermocline. For cruises T-311 and T-240 the feature appears to be somewhat masked, perhaps by the presence of internal waves. A physical basis for this thermocline dip is that while as a whole the thermocline surface is not level with respect to the earth gravity, it is sufficiently level near the speed axis to reflect the rapid change in the height of the sea surface there. Previously, Pillsbury (1890) noted this feature for the level of no motion and the speed axis.

The relation of the thermocline dip with the speed axis implies that while the wind stress is the ultimate driving force of the Florida Current, the speed axis is directly associated with the distribution of water mass. Of the five velocity transects (the curves give the uncorrected speed of the northerly components of the Current) two show the "familiar" profile of a single speed axis while the remaining three (T-311, T-315 and T-323) have profiles with two velocity maxima.

Velocity and surface temperatures. The sea surface temperatures obtained by means of the bucket thermometer are plotted in Figure 21. The table below gives the net sea surface temperature change from the Miami sea buoy to the point eastward at longitude 79° 55' for all five cruises and the corresponding average current speed (uncorrected GEK measurement) for the same space intervals:

TABLE 4

Cruise	Net Temperature Change (°C.)	Average Current Speed (cm/s)
T-240	0.0	65
T-311	0.3	110
T-315A	0.9	140
T-320B	0.1	70
T-323	0.8	125

The table indicates a tendency for greater average speed to associate with greater net temperature change. It is as if the sea surface temperature gradients are proportional to the slopes of the sea surface, and this should be so if the temperature distribution is the primary factor in the distribution of mass. (Available surface salinity data support this and indicate that temperature is the controlling factor.) Perhaps the inference can be made that, as with the relation of the thermocline dip to the speed axis farther offshore, the current nearer shore (in particular from the Miami sea buoy to 79° 50' W longitude) is also closely associated with the distribution of mass. This would imply that the processes of the merging of the two speed maxima into one or the splitting of one maximum into two are closely related to the mass distribution. These observations will have an important bearing on the interrelationship of wind stress, mass distribution, and the dynamics of the Florida Current. No obvious relationship has been noticed between surface temperature and a biaxial current.

If one may assume that the speed axis to which a thermocline dip is associated is the speed axis of the current, then the speed axis is seen in Figure 19 to oscillate within a zone two to three nautical miles of each side of longitude 79° 47' W. It is the appearance and disappearance of the other speed maximum on the left side of the current which gives the impression that the speed axis oscillatesmore widely.

Another feature of interest may be seen in Figure 21 giving sea surface temperatures. The sea surface temperature, as one goes eastward from Miami, may rise steeply to a maximum as in cruises T-311B and T-323 or it may change but little as in T-320B. The T-240 and T-315A cruises show sea surface temperature varying in still other ways. The feature to note is that the

so-called temperature axis is discernible only in T-311 and T-323.

Velocity shear and temperature gradient. Another manifestation of the association of surface current to mass distribution is the relation between the sharpest horizontal temperature gradient observed at 100 and 200 meter depths and observed zone of strongest current shear at the surface. This relation has been observed in most of the transects. (See Figures 1, 2, 11, 12, 14, 15 and 16.) In all cases with the exception of Figure 10 the area of greatest horizontal surface velocity shear on the west side of the axis lies above the region of greatest horizontal temperature change at 100 and 200 meters. Figure 13 shows the area of greatest temperature change slightly west of the maximum surface velocity shear. The observations in Figure 10 do not seem to fit into the general pattern as shown quite clearly in the other figures. With such high surface velocities so close to shore, there must have been a larger maximum shear much closer to the Miami shore than usual, which would mean that the area of greatest horizontal temperature change at 100 and 200 meters was well to the east of the velocity shear.

No obvious relationship has been found so far between temperature and velocity structure on the east side of the axis.

Direction of flow. According to observations by the GEK the directions of flow in the Straits of Florida is not always true north. Most of the observations show a flow with a small easterly or westerly component. Figure 20 has been devised to show the direction of flow for all the observations. The horizontal scale indicates direction in degrees of the compass, and the vertical scale represents the longitude with west at the bottom and east at the top.

In December the flow was close to 000° in midstream, with an easterly

component on the east side. In February all the observations but one showed easterly components. In midstream the flow was generally towards 017°. In March there were easterly components from 78° 50' W eastward, and westerly components along the western edge and easterly components along the eastern edge with directions very close to true north in midstream.

For the winter and spring months most of the observed current directions had an easterly component from 79° 55' W eastward. The easterly component is small between 79° 55' W and 79° 35' W, the region of highest surface velocities, but they increase in magnitude as the Bahama Banks are approached. For this latitude a majority of easterly components would be expected due to centrifugal force. Further north in the Straits the Current may show increased westerly components. The greater part of the observations along the western edge showed a small westerly component. Tidal effects influence the direction of flow especially near land. Drift cards in plastic envelopes have been sent adrift, but none has been returned. A relationship between direction of flow, width of current, transport and lunar phase and declination has been sought but without results.

Starting with Pillsbury, almost all studies on the Florida Current contain references to the lunar effects on the Current. Even the local seamen relate the velocity of the Current with the phase of the moon. Present data on this aspect are inconclusive.

Future plans. It is intended to continue this type of current observation thus completing a yearly picture of current velocity, position of axis and axes, directions of flow and transports. A Direction Range Finder and radar has recently been installed on the vessel so that accurate fixes may be obtained when out of sight of land, thereby eliminating one of the

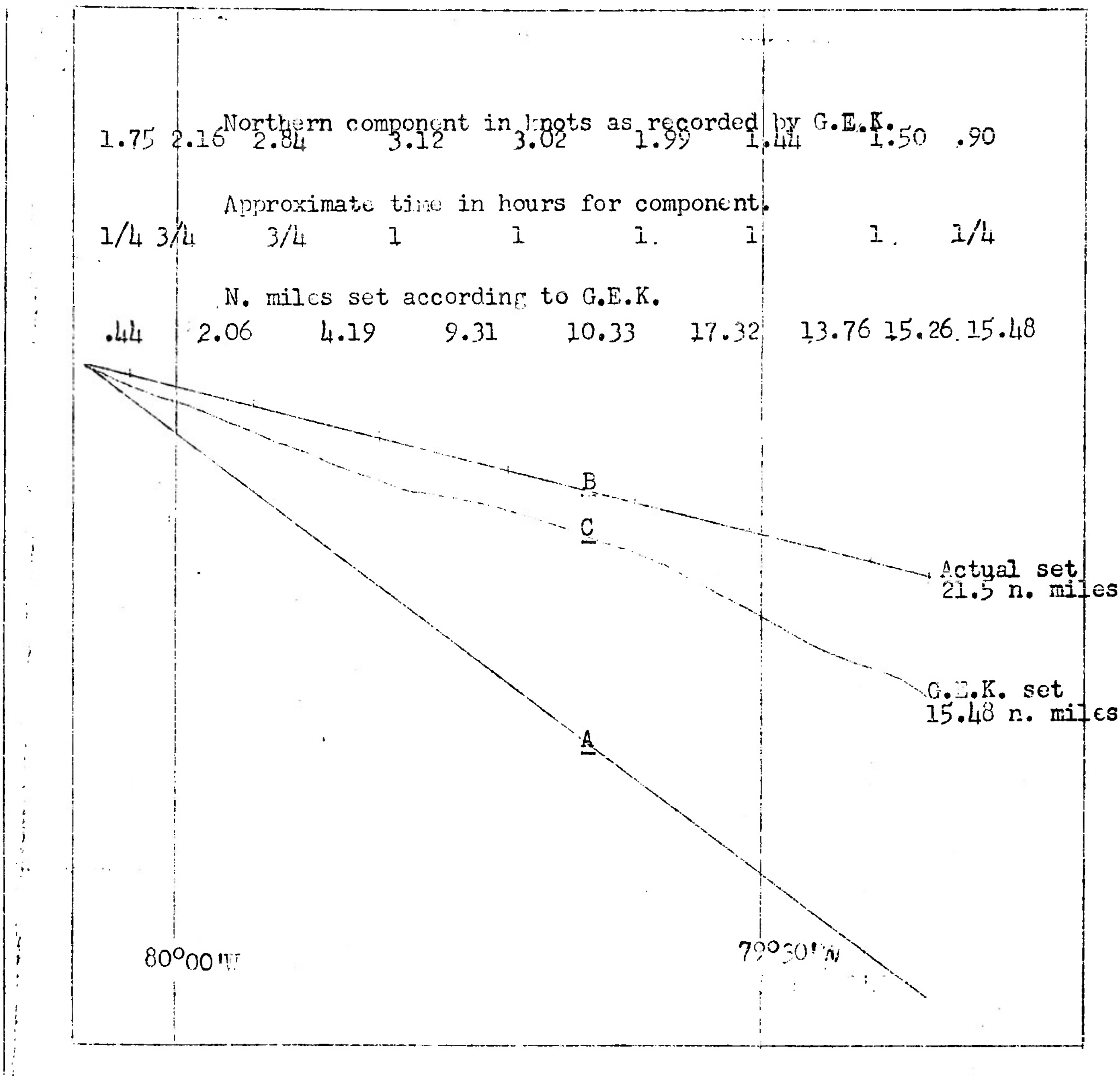


Figure 18 A TYPICAL G.E.K. TRANSECT OF THE FLORIDA CURRENT
<u>A</u> HEADING OF SHIP <u>B</u> DEAD RECKONING COURSE
<u>C</u> COURSE AS INDICATED BY ACCUMULATED G.E.K. FIXES

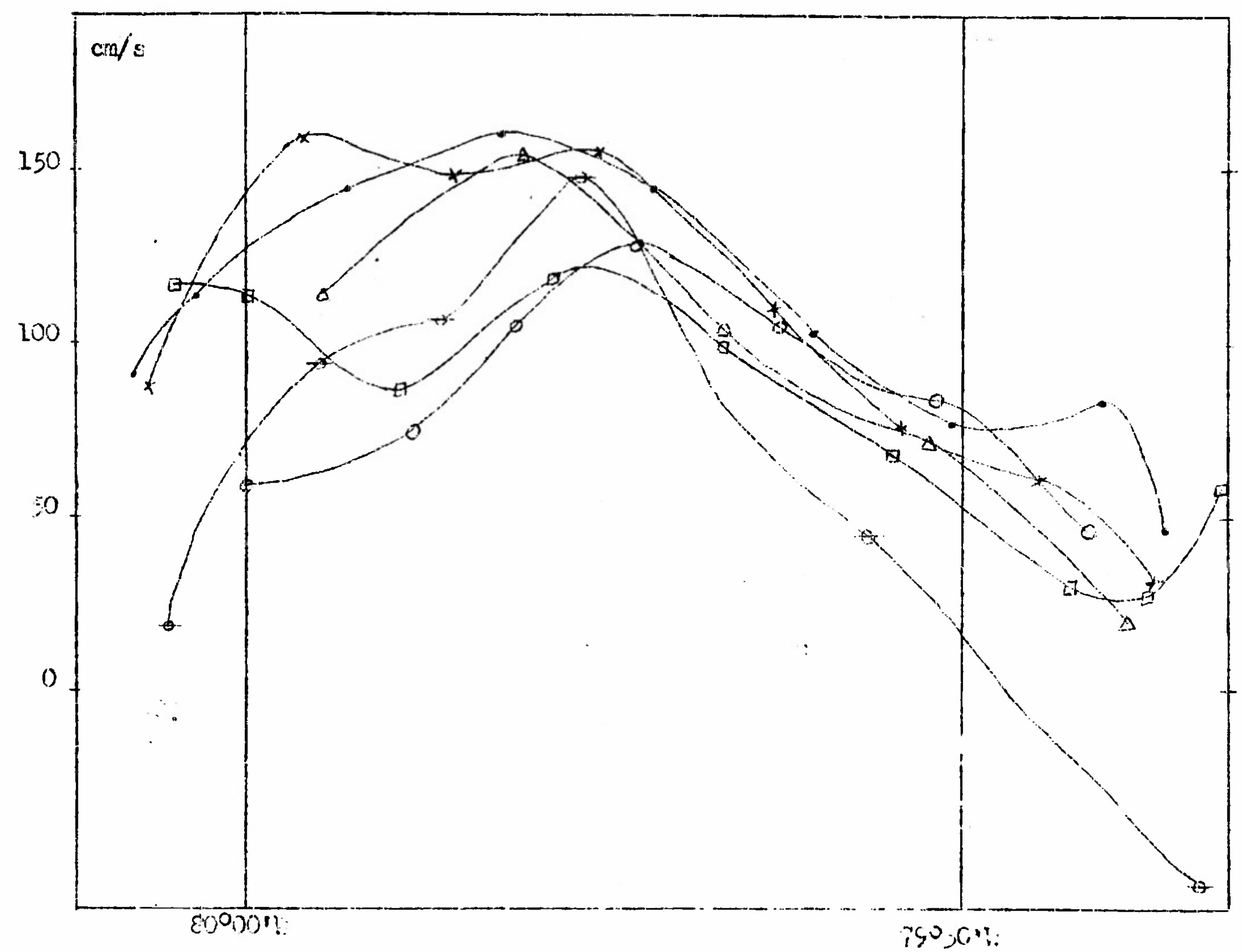


Figure 19. G.E.K. VECTORS FOR CRUISES T-240, 311, 313, 315, 320, and 323.
○ □ △ x ⊖ ●

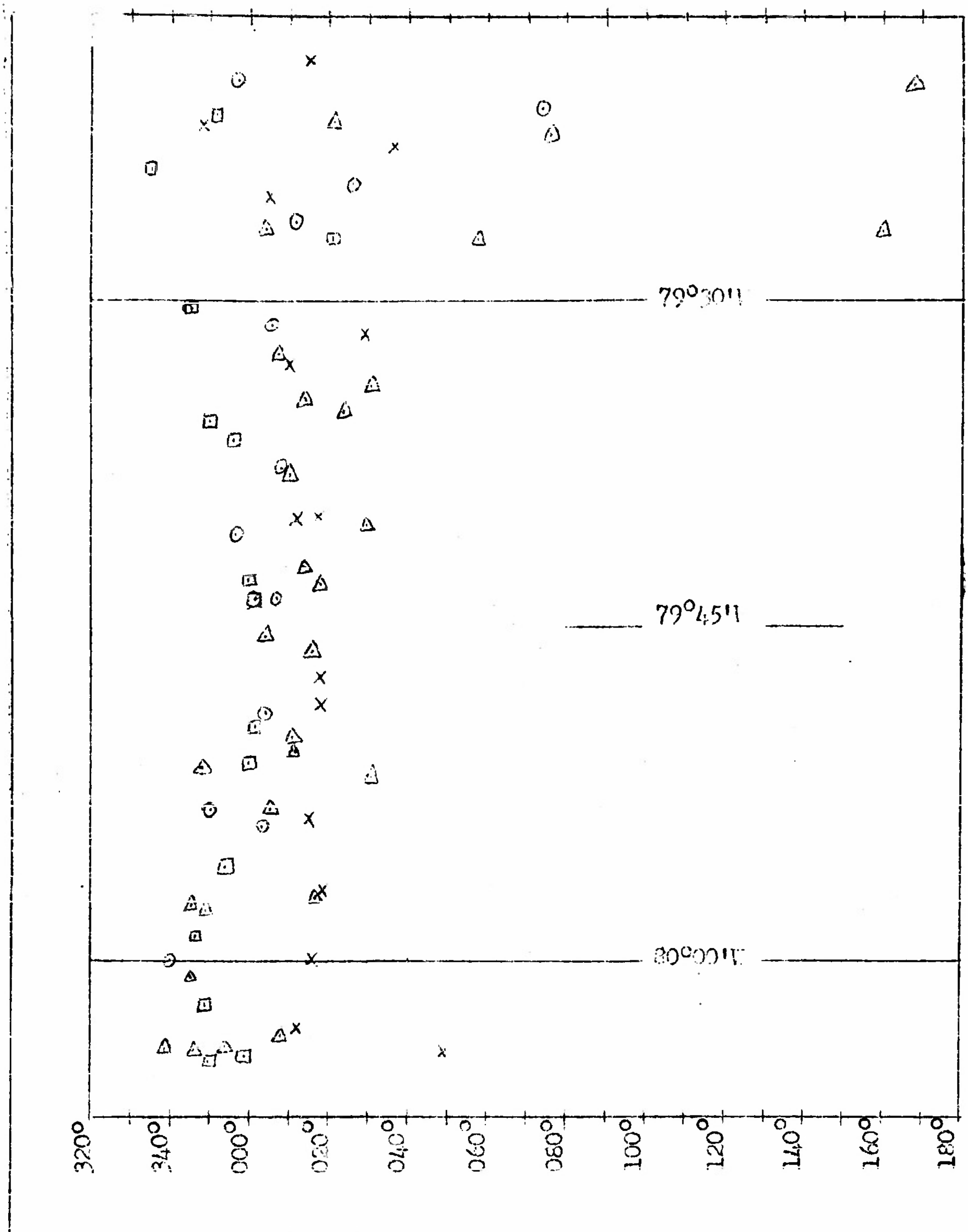


Figure 20. DIRECTIONS OF OBSERVED FLOW ACROSS THE FLORIDA CURRENT
December 1952 o February 1953 x
March 1953 △ April 1953 □

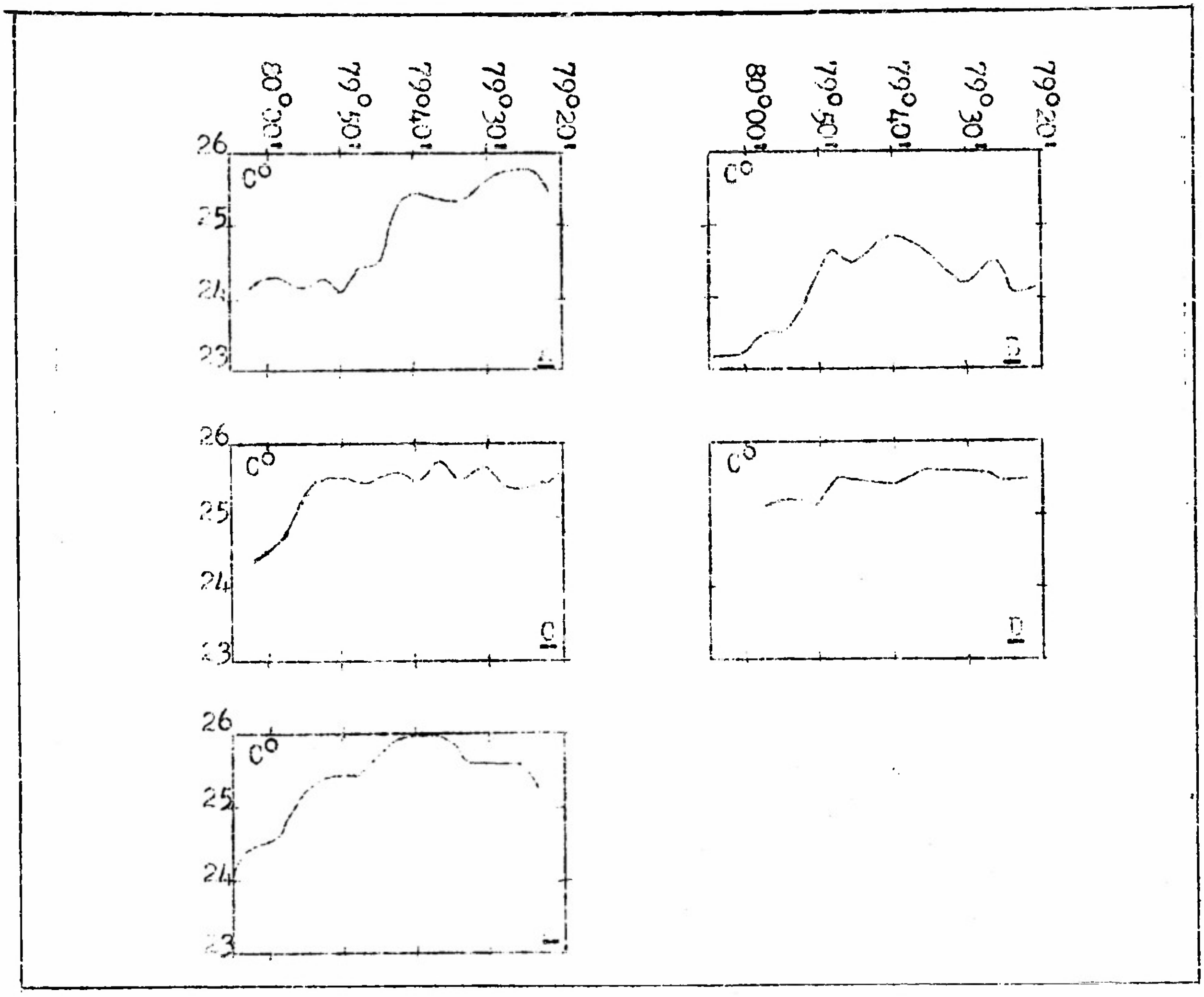
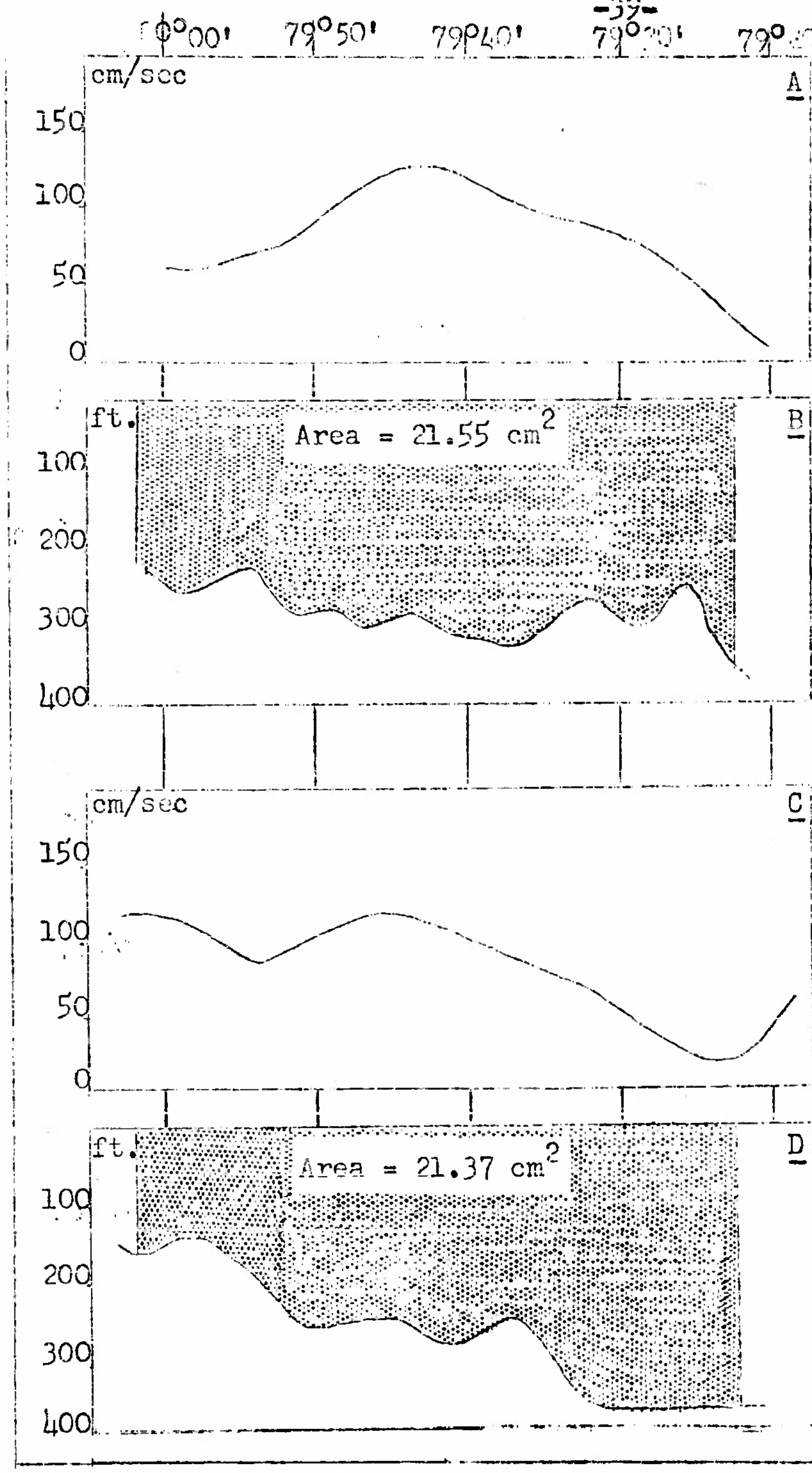


Figure 21.
Surface (bucket) temperatures across the Florida Current.

A T-240
B T-311
C T-315
D T-320
E T-323



Mean Current Velocity
94 cm/sec.

Transport
40.5 million cu m/sec.

Mean GEK "K"
2.16

See Figure 25 for bathythermograph traces

Mean Current Velocity
101 cm/sec.

Transport
43.5 million cu m/sec.

Mean GEK "K"
2.2

See Figure 26 for bathythermograph traces

Figure 22. A GEK VECTORS. B DEPTH OF FIRST STRONG THERMOCLINE
Data from Cruise T-240 Miami to Cat Cay December 22, 1952.
C GEK VECTORS. D DEPTH OF FIRST STRONG THERMOCLINE
Data from Cruise T-311 North Rock to Miami February 17, 1953.

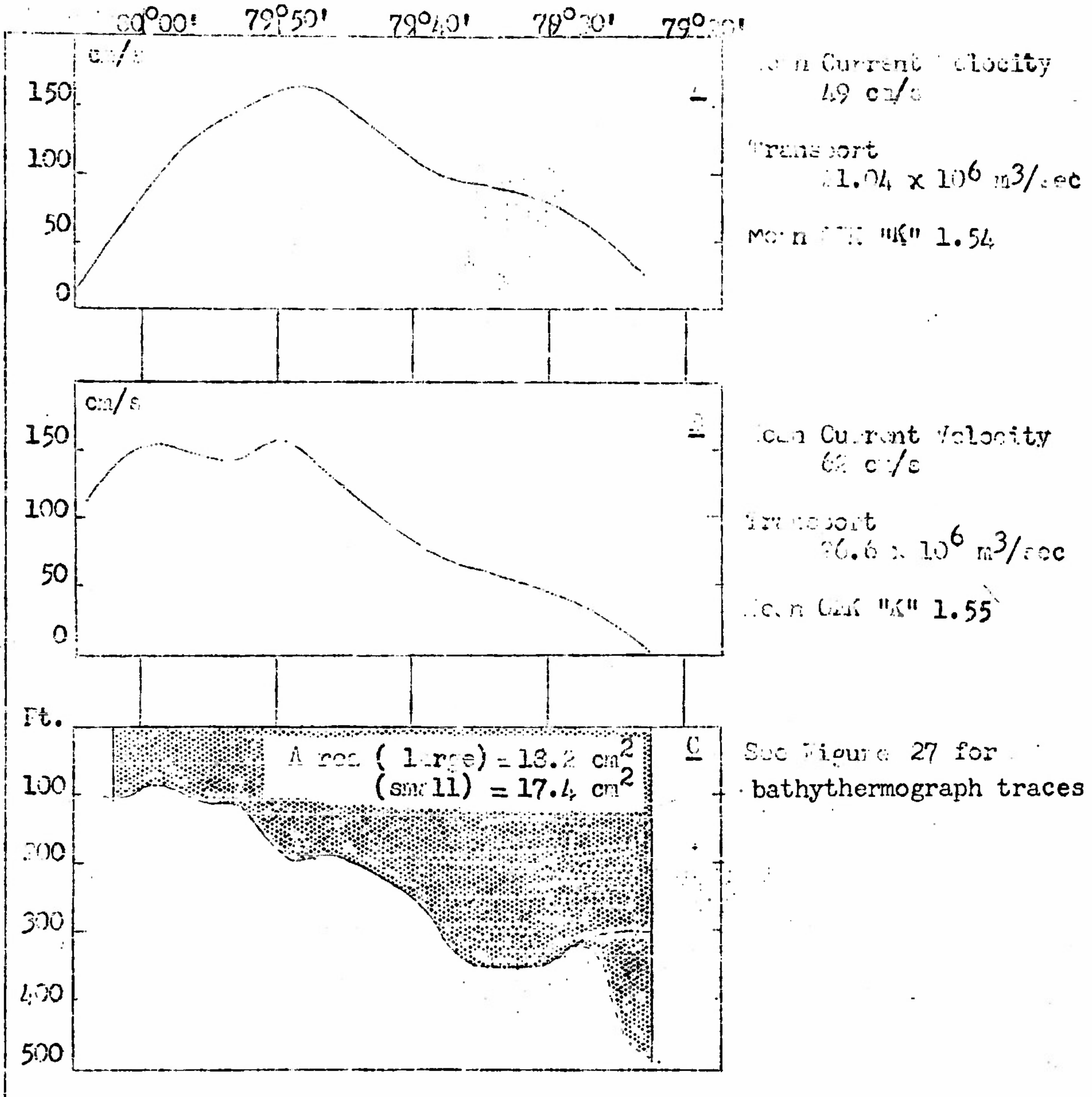
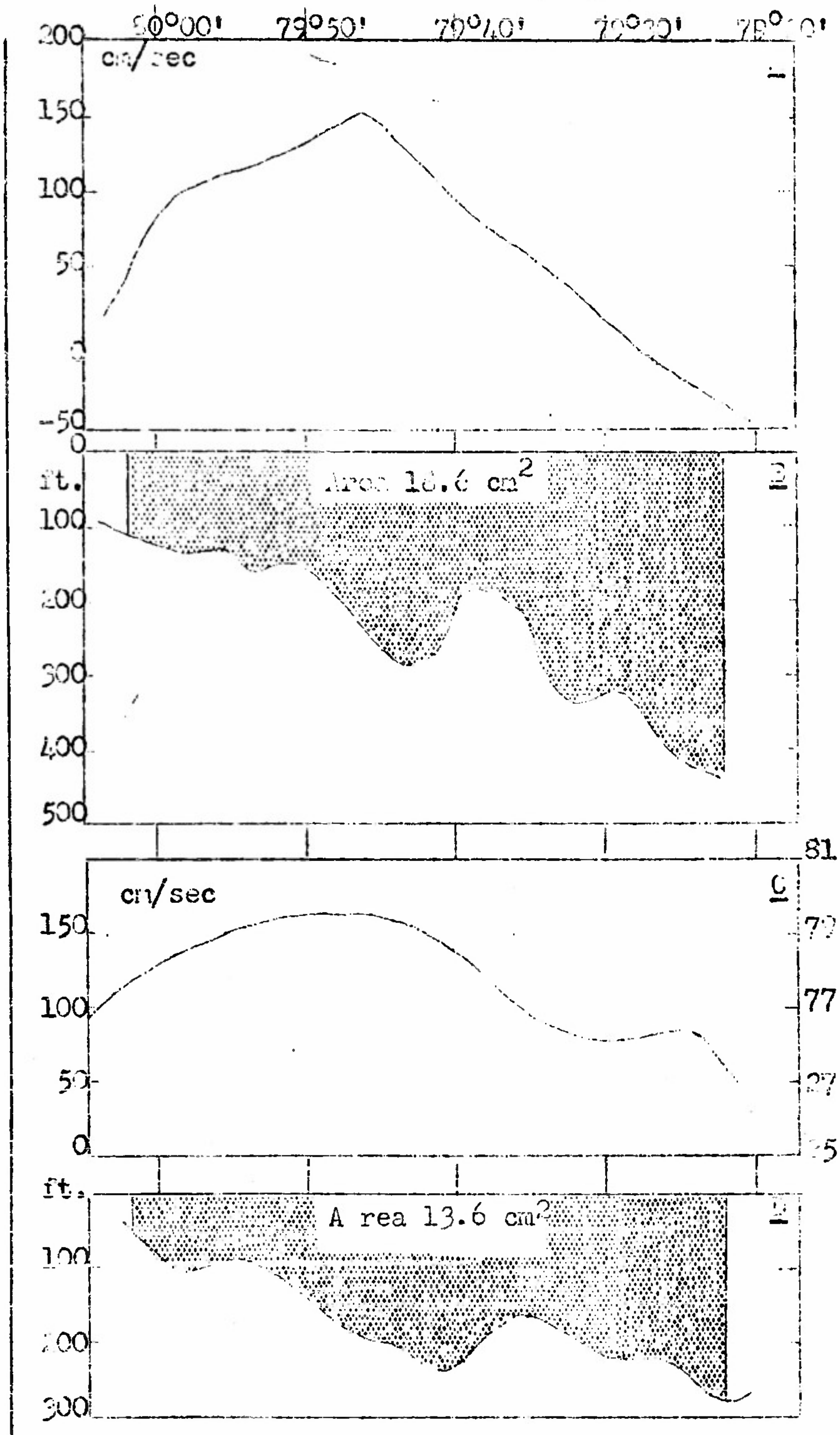


Figure 23. A G.E.K. VECTORS Data from Cruise T-313 Cat Cay to Miami Feb. 27, 1953.
B G.E.K. VECTORS C DEPTH OF FIRST STRONG THERMOCLINE
Data from Cruise T-315 Miami to Cat Cay, March 1?, 1953.
1 cm^2 = 274,500 ft^2.



Mean Current Velocity
57 cm/sec

Transport
?4.5 x 10^6 cu m/sec

Mean GEK "K" 1.84

Depth of Main Thermocline
See Figure 28 for B.T. traces

Mean Current Velocity
53.5 cm/sec

Transport
?3 x 10^6 cu m^3

Mean GEK "K" 1.39

See Figure 2 for Bathythermograph.

Figure 24. A GEK VECTORS. B DEPTH OF FIRST STRONG THERMOCLINE
Data from Cruise T-3?0 Cat Cay to Miami March ?6, 1953.
C GEK VECTORS. D DEPTH OF FIRST STRONG THERMOCLINE
Data from Cruise T-323 Miami to Cat Cay April 28, 1953.
1 cm^2=274,500 ft^2

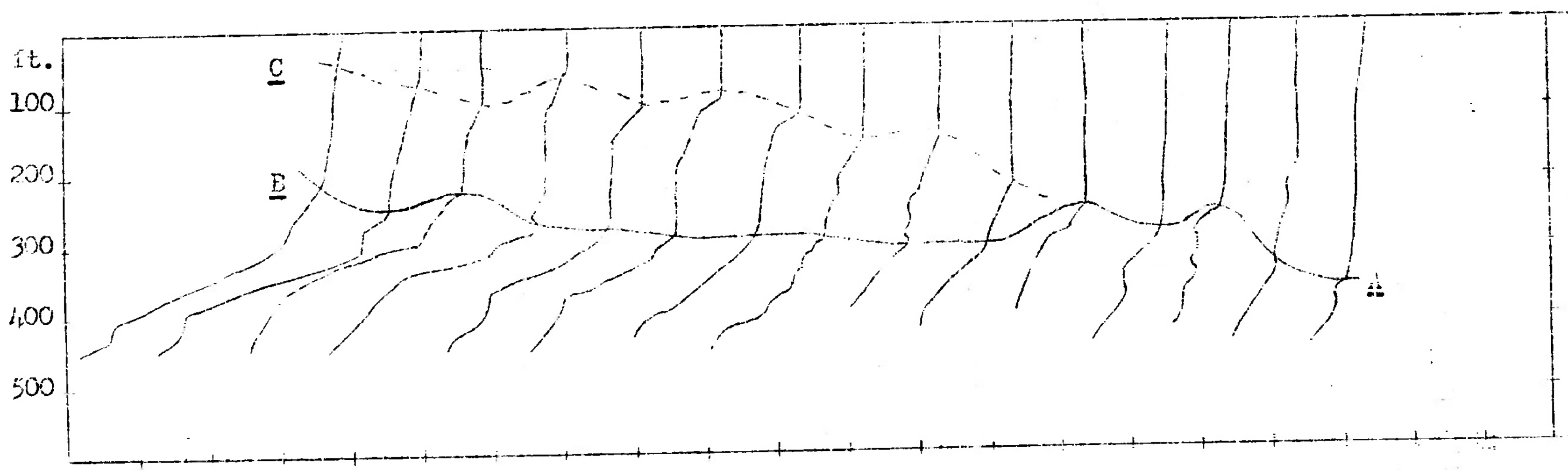


Figure 25 T-240 BATHYTHERMOGRAPH TRACES
1cm = $5^{\circ}F$

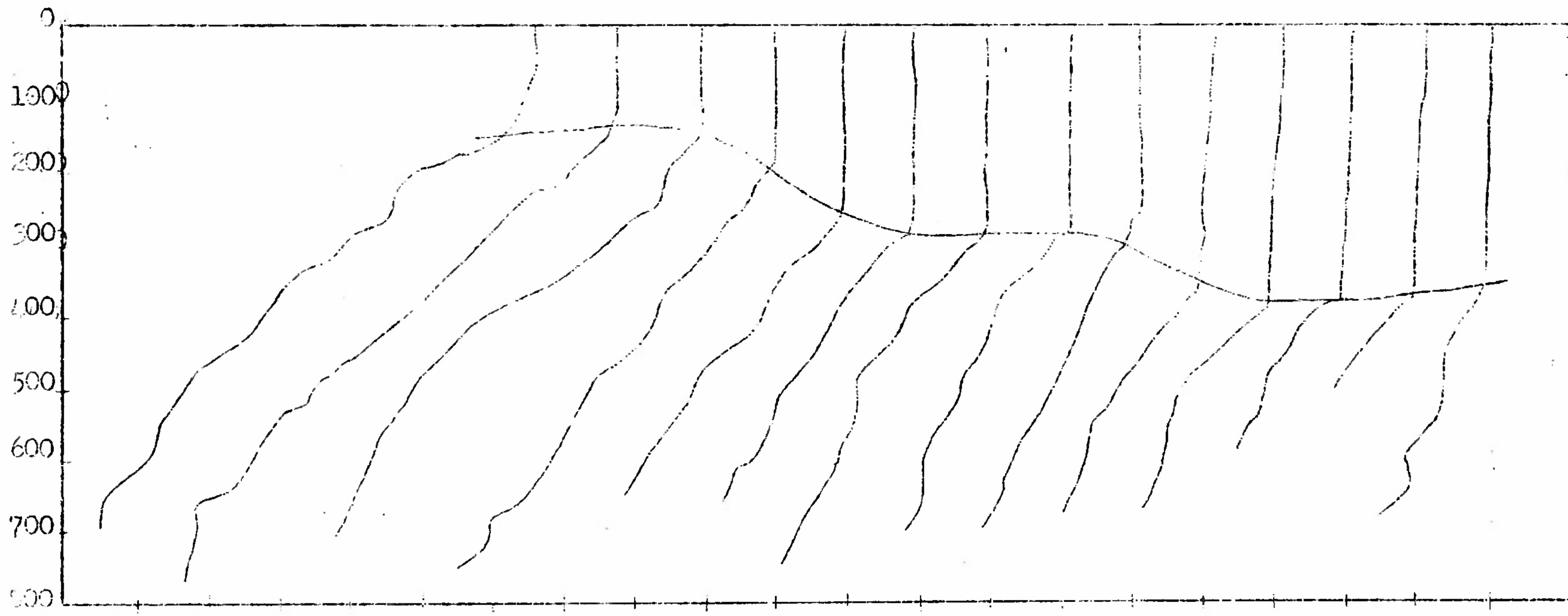


Figure 26. T-2113 BATHYTHERMOGRAPH TRACES
1 cm = 5°F.

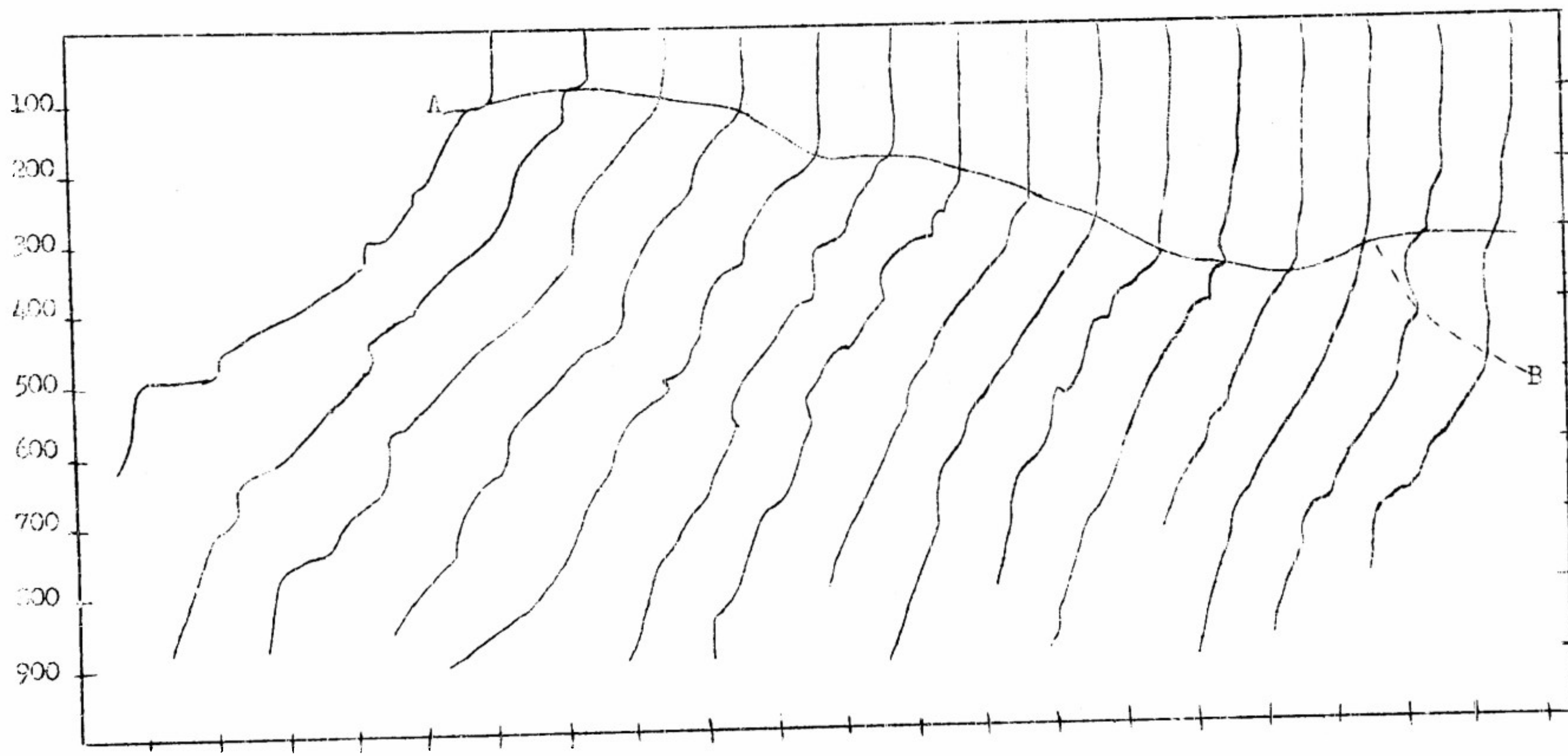


Figure 27. T-315A BATHYERMOGRAPH TRACES
1 cm = 5°F.

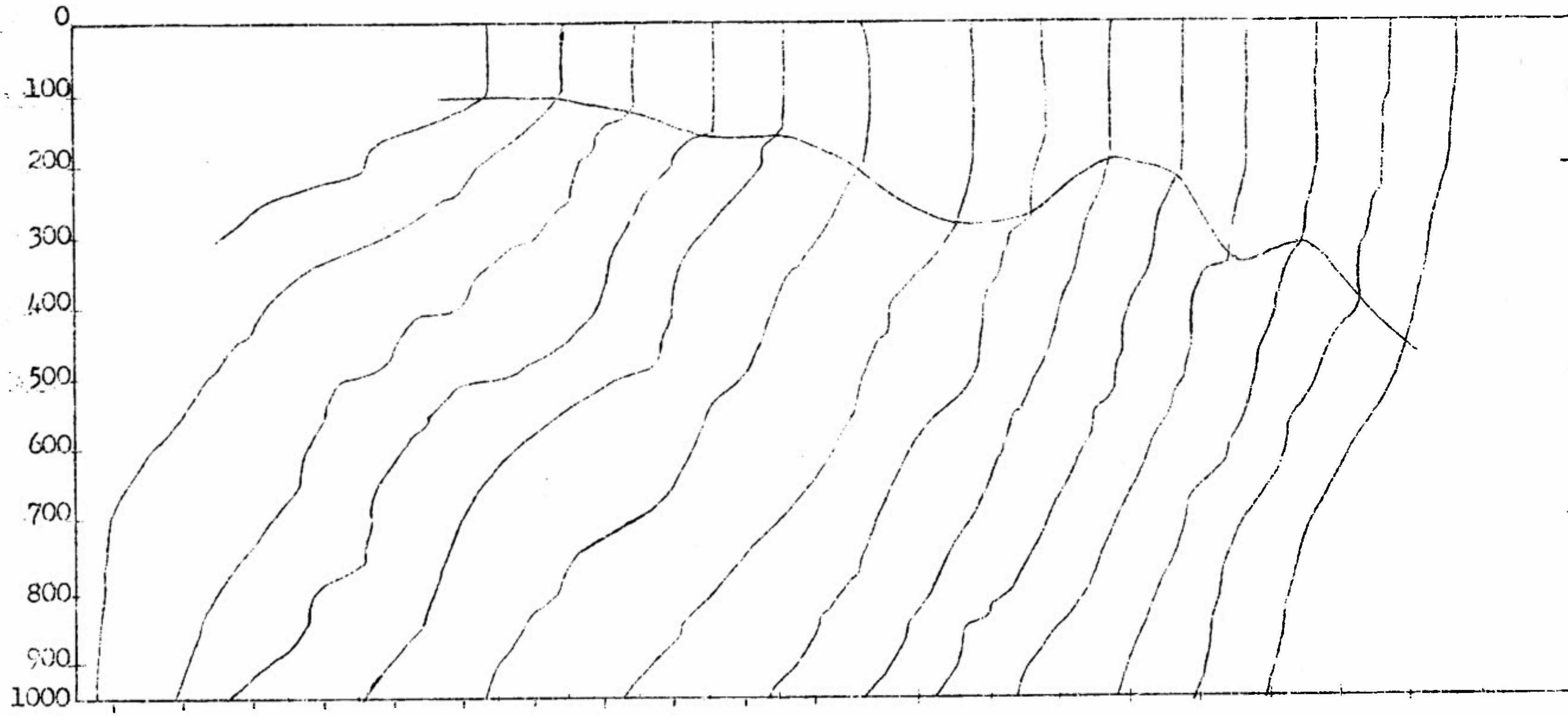


Figure 28. T-220B BATHYTHERMOGRAPH TRACES
1 cm = 5°F.

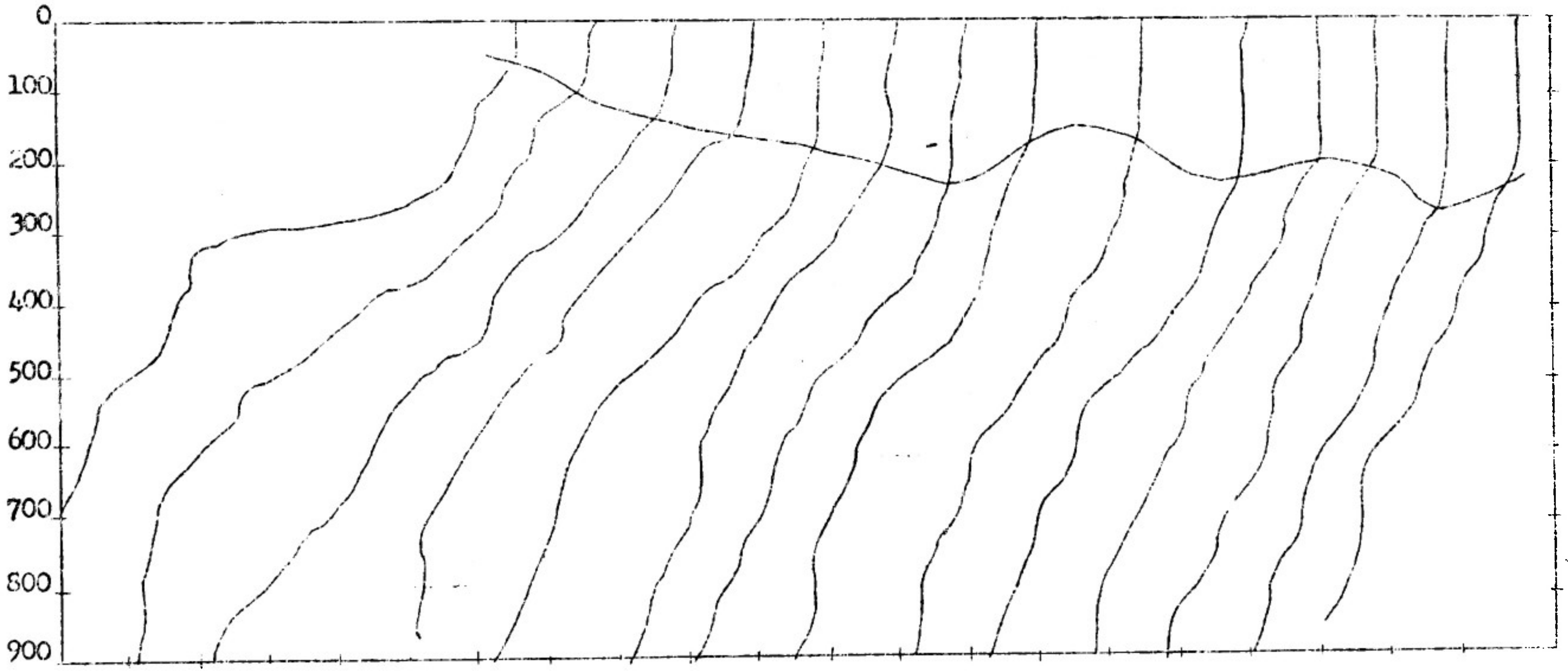


Figure 29 T-323 BATHYTHERMOGRAPH TRACES
1 cm = 5^{o}F.

assumptions in the transport computations.

This project is trying to obtain a bathypitotmeter in order to measure the variation of speed with respect to depth. This would be valuable in determining the relation between GEK velocities, transports and the depth to the first strong thermocline.

Observations on the Western Edge of the Florida Current

No continuous plan of observations has yet been attempted along the western side of the Current, but a few notes are worth presenting from this area at this time. It is an area of large changes, in temperature, current velocity, perhaps of current direction, and in color. There may be an area of convergence just west of the 100 fathom line.

One cruise was made in this vicinity in order to compare surface currents as measured by a free floating pole buoy (12 feet, 3 by 6 inches, weighted at the bottom by a 10-foot rope and scrap iron; above the surface was a 2-foot stick with small flag attached), with those made with the GEK. Below are the results. These observations were made along Miami Beach. The first set was made as close to the Miami sea buoy as possible.

TABLE 5

Depth Fathoms	Drift Buoy Velocity cm/sec	GEK Velocity	K Factor
55	153	87 average of 3	1.76
130-140	224	162 average of 2	1.38
150	211	152 average of 3	1.39

On March 17, 1953, more observations were taken in what might be a convergence area (see Figure 30). The vessel passed through the Miami jetty at 1910. Immediately two areas of color change were noticed about 200 yards apart. Slicks running north-south were along the sharpest color change that ran close to the Miami sea buoy. Just to the west of this buoy was a heavy crude line made up chiefly of <u>Sargassum</u> weed.

The same type of drift buoy was used to measure the current velocity and direction. This was set adrift in blue water (Gulf Stream water) and drifted 1.9 miles in an hour toward the sharp color change. It was then placed slightly to the west of the color change, in the strip of greenish water. In an hour it had drifted 0.5 miles to the color change. The buoy was left to drift on the color line, and its position was found every hour. By 1240 it had drifted 0.7 miles and by 1343 it had drifted 1.2 miles further. Between 1352 and 1452 it drifted 1.2 miles, and by 1600 it had gone another 0.9 miles. All this time it remained on the very distinct color change line.

Slack ebb was at approximately 1100 and maximum ebb flow at 1400. The increase in velocity of the buoy is related to the increase in ebb flow at this time. During the third drift period it was noted that the area between the two color changes had decreased to about 100 yards. The eastern color change line, the stronger, showed a crude line and north-south slicks. The western line also showed north-south slicks, but the color change had weakened. By 1230 the area in between the two lines had vanished leaving a slick area of about 25 yards. These slicks were no longer north and south; they showed no pattern of alignment. The wind had shifted into the east and was between Beaufort Force 2.

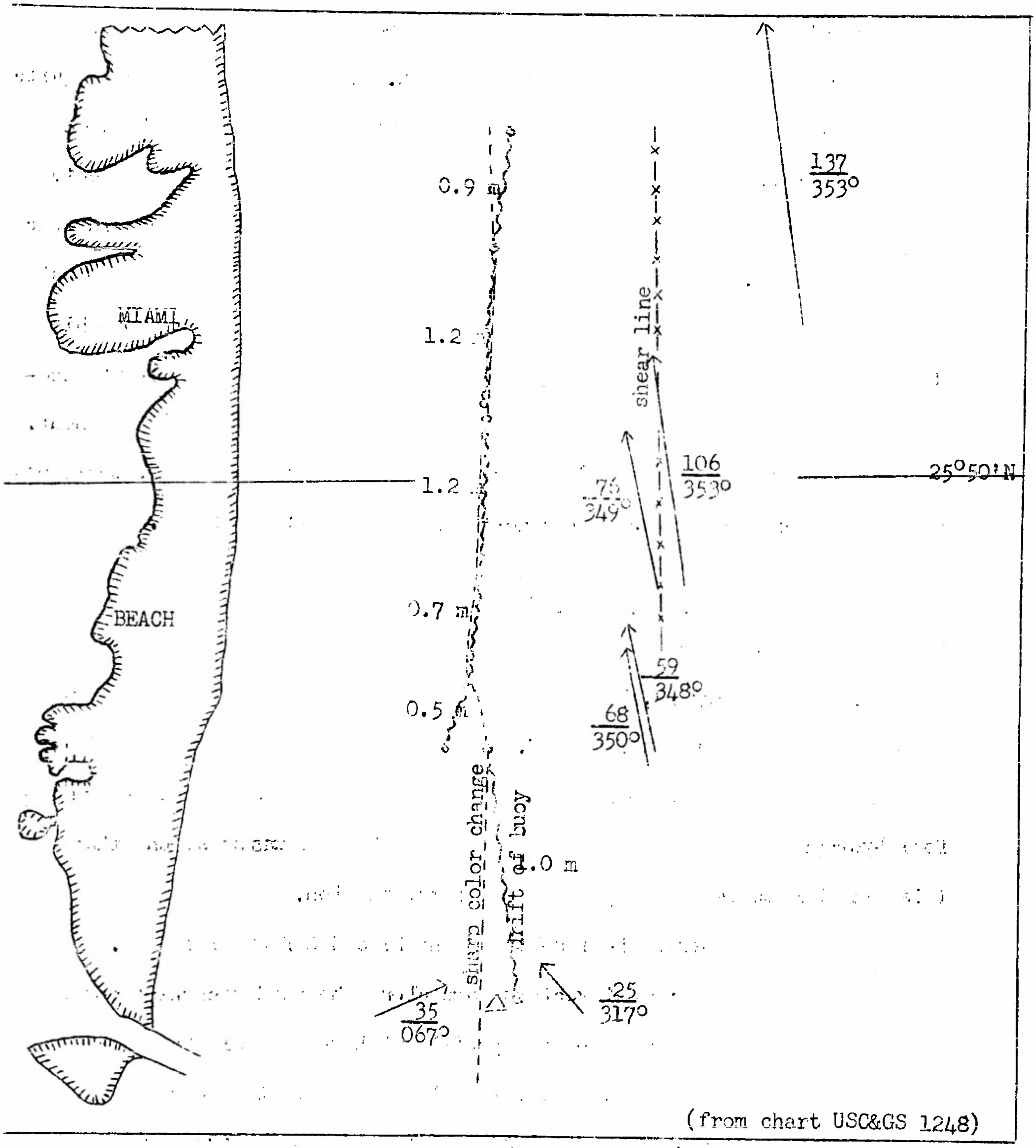


Figure 30 WESTERN EDGE OF FLORIDA CURRENT
March 17, 1953.

In between times of checking the location of the drift, GEK observations were made in deeper water to the east. This data seemed to be quite consistent. The direction of flow had a slight westward component which would account for the crude line just to the west and would also indicate an area of convergence. An area of strong velocity shear was recorded four times by the GEK. This area was so marked on the record that it was possible to predict its location the fourth time that it was passed. East of this shear zone the observed current assumed a flow with a smaller westerly component, and further to the east it may have taken on an easterly component. This would indicate an area of divergence. If this were the case, there may exist here a band of water moving north in a spiral flow pattern.

Antilles Current Investigation

An attempt was made to discover the existence of the Antilles Current. On February 13, 1953, the T-19 left Harbor Island at Eueuthera Island steering a course of 055° T. Bathythermographic observations were made every half hour and GEK fixes were made every hour. On the return leg four hydrographic stations were planned, but the wind was so strong that this plan had to be given up after the first station.

Figure 31 presents the results of the BT and GEK observations. The arrows, representing current vectors, are along the dead reckoning course of the ship. The temperature-depth profile with depth scale has been drawn beneath the current vectors. The return leg, slightly to the north, shows a few current vectors, Because of high winds and fish attacks on the GEK cable, operations had to be suspended. The first hydrographic station was made at the end of the 055° course at 26° 51' N, 74° 11' W. At that time the opinion was that the Sargasso Sea had been reached, and so there was no

point in going further to the northeast. The assumption was correct as this station produced temperature-salinity correlations that correspond to those of the Sargasso Sea, as shown by Iselin (1936). The T-S correlation for the water down to 400 meters does not duplicate Iselin's figures as closely as does the water below that level.

Several conclusions have been drawn from this cruise. At the time of observation no "organized" Antilles Current was found. In its place two distinct current patterns, having apparent cyclonic patterns, were found. These are closely associated with the distribution of density as given by the BT observations down to about 700 feet. (See A and B on Figure 30 for location of these two current patterns.) At the location of the cyclonic circulations, the thermocline is seen to rise to its shallowest depth in accordance with the geostrophic current principle. Otherwise, the thermocline as a whole remains level; that is, its depth at Eleuthera is approximately the same as at 26° 51' N, 74° 11' W. There was no strong inclination as found in the Florida Current. The observed GEK current of the outbound and inbound legs are in accordance and appear to have been influenced by the winds, but not so much as to alter the current as determined by the mass distribution. For example, where the 73° F isotherm rises to the surface, the GEK readings on the outbound leg were opposed by the light northerly winds, while at the same vicinity on the return leg the GEK currents were following the strong southeasterly wind.

On May 17, 1953, another attempt was made to study the Antilles Current region. It was planned to take a northeasterly course from the northernmost tip of the Little Bahama Banks. Several fish attacks on the GEK cables so lacerated them that they became inoperable. Lacking this type

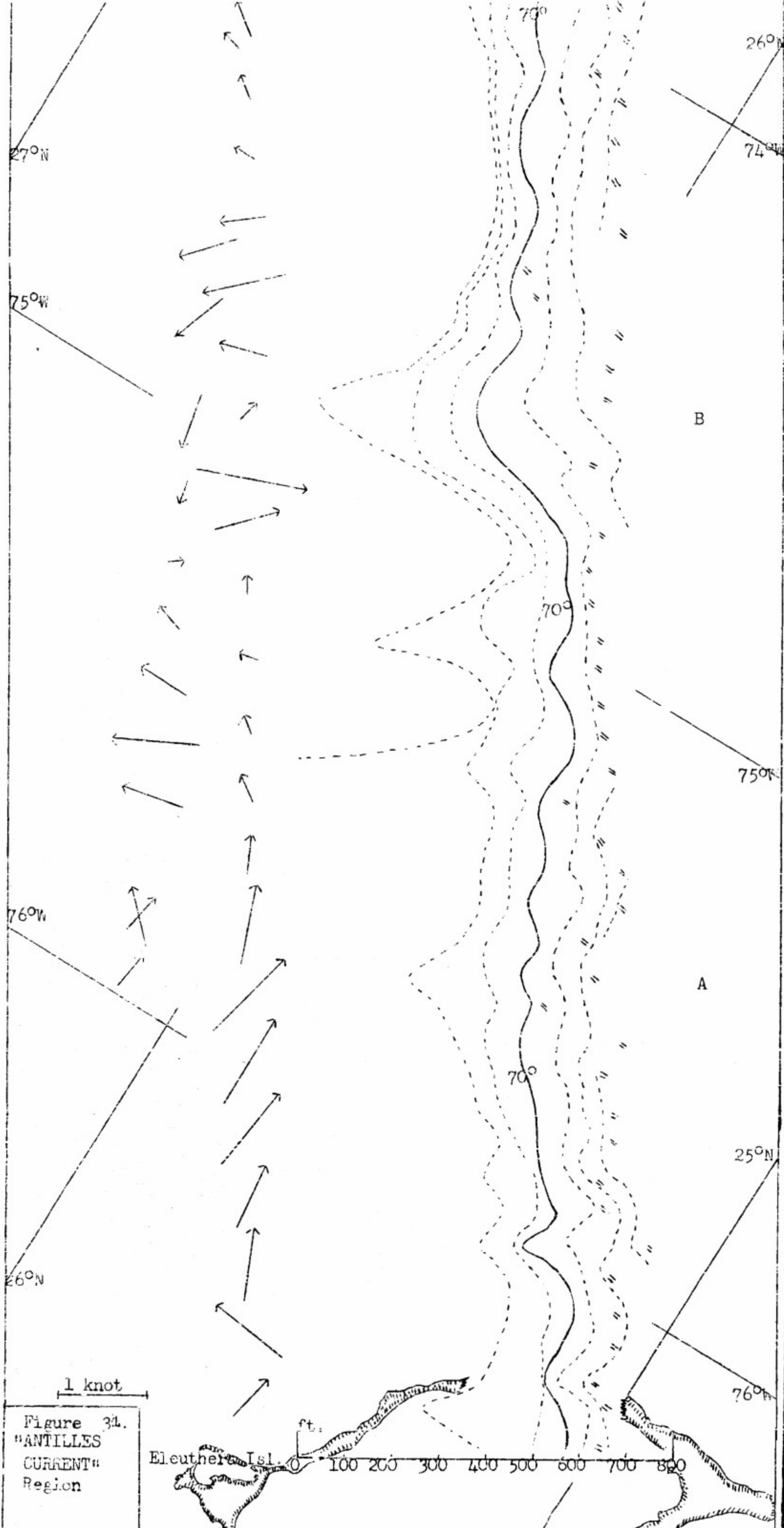


Figure 31.
"ANTILLES
CURRENT"
Region

of data it did not seem advisable to continue the cruise, as the correlation between GEK and BT data on the first Antilles cruise had been essential to determine the current patterns. Also the 400-cycle power supply converter for the Loran burned out.

BIBLIOGRAPHY

FUGLISTER, F. C., and L. V. WORTHINGTON.
1951. Some results of a multiple ship survey of the Gulf Stream. 3(2): 1-14.

MALKUS, W. V. R. and M. E. STERN
1952. Determination of ocean transports and velocities by electromagnetic effects. J. Mar. Res., 11(2): 97-105.

PATULLO, J.
1952. Mixed layer depth determined from critical gradient frequency. Scripps Institute of Ocean. Ref., 52-25.

PILLSBURY, J. E.
1890. The Gulf Stream. U.S. Coast and Geodetic Survey, Appendix No. 10-1890.

STOMMEL, H.
1948. The theory of the electric field induced in deep ocean currents. J. Mar. Res., 7(3): 386-392.

SVERDRUP, H. U., MARTIN W. JOHNSON, and RICHARD H. FLEMING.
1948. The Oceans. Prentice-Hall, Inc., New York.